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Climate, Agriculture and Drought: Miscellaneous Papers

By

Staff Members

of the

MIDWESTERN CLIMATE CENTER

Research Report 91-01
March 1991

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INCORPORATING WEATHER AND CLIMATE DATA INTO INTEGRATED CROP MANAGEMENT SYSTEMS

by
Steven E. Hollinger[1]

INTRODUCTION

Agricultural technology has greatly increased the productivity of American agriculture during the past several decades. The higher yields and larger production are a result of better hybrids and varieties, larger application of fertilizers, and better pest control using chemical pesticides. The larger applications of fertilizers and pesticides have resulted in a threat to our environment. This threat was due to an attitude of "if a little is good, more is better." An increasing awareness of environmental concerns by producers and the general public has resulted in the agricultural community reevaluating our recent production practices, and the creation of the Low Input Sustainable Agriculture (LISA) program. Regardless, whether a producer's philosophy is LISA or high input agriculture, the main concern is whether he/she is making a profit.

Agricultural research has determined which production practices will result in good production over many years. However, it has not addressed the issue of year-to-year variations in production. Granted, our agricultural extension personnel and production managers are concerned with the year-to-year variations; however, the mountains of multi-year experiments have not been examined for how weather has impacted the various experiments or recommended production practices. This has been left to the "art of production," where a producer learns how weather impacts production during the actual process. Such an approach in times of narrow profit margins results in unnecessary economic losses. Therefore, it is necessary to develop procedures to determine how a producer can use climate and weather information in timing production practices for optimum efficiency.

Climate and weather information can be useful only in light of the complete crop system. The crop system includes the weather, soil and water conditions, crops grown, weeds and insects present, physical and economic resources available, and the management expertise of the producer. Weather, the continuing daily changes in the atmospheric conditions, impacts each of the other pieces of the system. For example, it is the pattern of rainfall that determines the natural soil moisture available to the crop, and whether the

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producer must apply additional water through irrigation. Weather also impacts the rate of crop and weed growth and development. Many insects that are crop pests migrate into one region from another. It is the weather patterns and wind directions that determine the time of arrival and extent of emigration of these insects. Weather conditions determine the survival rate and rate of development of those insects that do not migrate.

One might argue that a producer must have a 100% accurate picture of what these conditions were going to be throughout the growing season before the weather information would be of any value. A recent study by Sonka et al. (1986; 1987) demonstrated that even inaccurate climate and weather forecasts can be valuable to production agriculture. They concluded that climate and/or weather forecasts will have value to agricultural producers only if producers are able to 1) make a management decision based on the information, and 2) carry out the actions required by that decision. Thus, the forecast must be made early enough for the producer to complete the operation before the event occurs. The actual value of the climate or weather forecast is dependent upon the value of the crop, the potential yield loss (gain) as a result of the management decision and operation, and the cost of the particular decision and operation.

This paper will explore some methods that may be used to incorporate climate and weather information into agricultural production practices. Included are suggestions as to how climate and weather information may be used to form strategic and/or tactical plans to improve agricultural production efficiency. Strategic planning refers to long-range plans such as equipment purchases, manpower needs, and expansion plans. Tactical planning refers to seasonal and/or day-to-day operational plans.

CLIMATE AND WEATHER INFORMATION NEEDS

The weather variables important to agricultural production are: solar radiation, temperature (air and soil), relative humidity, wind, and precipitation. Evaporation is also important, but it can be computed using solar radiation, air temperature, relative humidity, and wind. Solar radiation is important since it is the ultimate driving force behind weather and the photosynthesis process. Rainfed or dry land agriculture relies entirely on precipitation for crop water. Just looking at precipitation does not give the entire picture, as the crop gets its water through roots from the water stored in the soil. Therefore, soil water might be included as a "weather" variable.

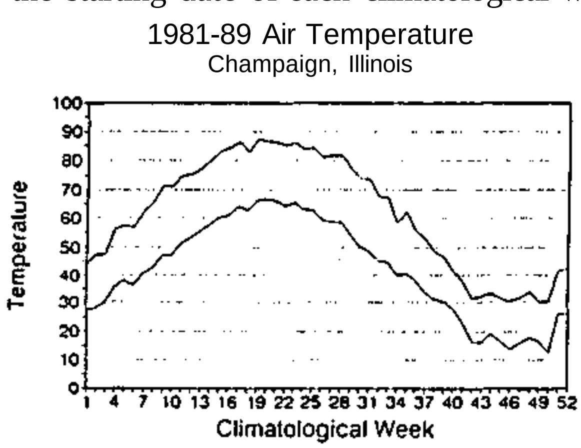
The above variables can be defined in terms of weather variables and climate variables. Generally, weather is defined as the current state of the atmosphere. In practice, it is used to refer to the recent past (up to one year), the present, and the near future (6 to

10 days). The term climate or climatology is the long-term average of the past weather record. Climate terms include the daily, weekly, and monthly averages; standard deviations; and probability of occurrences of the various weather events. These can include the average and standard deviation over a given period of the current year, or of a given period over several years. Normally, climate variables are developed over a period of 30 years with new "normals" calculated every 10 years at the start of a new decade.

Climate Information Development

Climate information can be divided into two classes: 1) raw data, and 2) derived data. Raw data consists of the normally measured variables such as temperature, precipitation, relative humidity, wind, solar radiation, soil moisture, and potential evapotranspiration. Derived data consists of computed values such as growing degree days, heat stress days, cold stress days, temperature humidity index, and heating and cooling degree days. Since most cooperative weather stations only measure daily maximum and minimum temperatures and precipitation, some of the potentially measured variables (i.e., evaporation, soil moisture) may be derived or estimated using various models.

The most common climatological data are the monthly means of maximum and minimum temperatures and total precipitation (Fig. 1). These data are too coarse for agricultural purposes. Weekly means, standard deviations, and probabilities are more useful since they allow the assessment of weather during critical crop growth stages. A problem with weekly data is that when the data are started on January 1 of each year, the actual days in the week change after February during leap years. For example, during a non-leap year, the 7-day period that includes the last few days of February and the first few days of March includes the days February 26 through March 4. In a leap year, this same week includes the days February 26 through March 3. To get around this problem, the climatological week has been defined. A "climatological year" begins on March 1 through March 7. The only problem this causes is that the last week of February is a "long week," 8 days in non-leap years, and 9 days in leap years. For most crops, this does not pose a problem. Table 1 gives the starting date of each climatological week during the year.



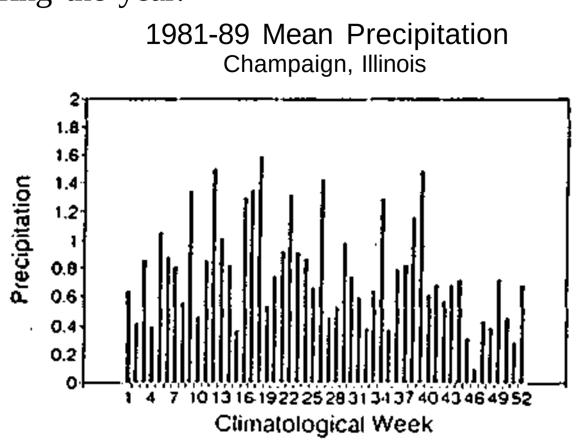


Figure 1. Example of 30-year climatological week means of temperature and precipitation for Champaign-Urbana, Illinois.

Table 1. Starting date of each climatological week

Week No.	Date	Week No.	Date
1	Mar. 1	27	Aug. 30
2	Mar. 8	28	Sep. 6
3	Mar. 15	29	Sep. 13
4	Mar. 22	30	Sep. 20
5	Mar. 29	31	Sep. 27
6	Apr. 5	32	Oct. 4
7	Apr. 12	33	Oct. 11
8	Apr. 19	34	Oct. 18
9	Apr. 26	35	Oct. 25
10	May 3	36	Nov. 1
11	May 10	37	Nov. 8
12	May 17	38	Nov. 15
13	May 24	39	Nov. 22
14	May 31	40	Nov. 29
15	Jun. 7	41	Dec. 6
16	Jun. 14	42	Dec. 13
17	Jun. 21	43	Dec. 20
18	Jun. 28	44	Dec. 27
19	Jul. 5	45	Jan. 3
20	Jul. 12	46	Jan. 10
21	Jul. 19	47	Jan. 17
22	Jul. 26	48	Jan. 24
23	Aug. 2	49	Jan. 31
24	Aug. 9	50	Feb. 7
25	Aug. 16	51	Feb. 14
26	Aug. 23	52	Feb. 21

A discussion of how the various climate statistics are developed is beyond the scope of this paper. Two texts that deal with the development of climate statistics are Panofsky and Brier (1968), and Haan (1977).

Use of Climate and Weather Information

For the purposes of this discussion, we will refer to weather information as the current state of the environment, 24- to 48-hour, 3- to 5-day, and 6- to 10-day weather forecasts. Generally, forecasters today can demonstrate reasonable skill in the 24- to 48-hour forecasts with decreasing skill as forecasts are extended out to 10 days. Unfortunately, it is these longer-range forecasts that are needed in the tactical planning of an agricultural production operation. Also, as the forecasts are extended further into the future, the forecasts are couched in more general terms such as "temperature 6 to 10° above normal with above normal to much above normal precipitation." Therefore, to make good use of the longer-range forecasts, one must know what the "normal" temperature and precipitation is for the period.

This is where climatology enters the tactical planning picture. As noted above, tactical planning can refer to the day-to-day or seasonal planning of an agricultural production operation. When used in the near term (day-to-day) planning, knowledge of the current pest, soil moisture, and weather conditions along with weather forecasts (24-48 hour, 3-5 day, 6-10 day) are necessary. Some day-to-day operations that might make use of these data are the rescheduling of field tillage operations, scouting for insect or other pest problems, and the timing of fertilizer and chemical applications. Agricultural forecasts in the 24-48 hour period will often include expected maximum and minimum temperatures, precipitation amounts, cloudiness, and wind conditions. The 3-5 day forecasts include an expected maximum and minimum temperature range, and precipitation type and amount expressed as a difference from normal. The 6-10 day temperature forecasts are expressed as degrees deviation from normal. The 6-10 day precipitation forecasts are expressed as above (below) or much above (much below) normal. These forecasts can be interpreted only in conjunction with climate data. Therefore, the producer or some advisor to the producer must make the appropriate computations to make the data more useful. The 6-10 day forecasts usually do not include any information relative to cloudiness or wind conditions.

Tactical seasonal planning will help provide a game plan for hybrid/variety selection, alternative crop selection, and fertilizer and pesticide programs. In general, a basic plan for each of these items is a part of the strategic plan. However, by taking note of the current soil moisture conditions and long-range weather forecasts (30- and 90-day outlooks), and considering the normal climate, adjustments to this general plan can be made. For example, if it is excessively wet during early spring and the 30-day forecast is for above normal rain, an estimated planting date can be determined using the work day climatology; current soil moisture conditions; normal rainfall adjusted for the wetter-than-normal forecast; and the time required to prepare the seed bed and plant the crop. Then "what if" questions can be asked to explore the options of hiring additional people and equipment, or changing hybrids/varieties based on the normal length of the growing season, and normal rate of crop growth and development.

Strategic planning involves the identification of types and amounts of resources necessary to insure a profitable operation with the climate that occurs at a given location. Both climate and soil information are needed to determine the potential amount of water available to the crop, feasibility of irrigation, the average number of work days each season, and the length of the growing season. With these data the number and size of tractors and implements as well as the number of employees needed to accomplish each task in a timely manner can be determined as a function of the number of acres under production. The selection of major crops and alternative crops can be determined using the climate and soil data, along with environmental requirements of the different crops. Climate and weather information are also important components of soil and water management decisions.

SOIL AND WATER MANAGEMENT

Soil and water management is an important aspect of an agricultural production system. Soil management may be defined as caring for the soil to maintain fertility, preserve topsoil, and provide a media that plant roots can penetrate so the plant can obtain the water and nutrients needed for its growth. Water management, in simple terms, is managing the earth surface to get water into the soil, remove unwanted water from the soil, and control the loss of water from the soil by the processes of evaporation and transpiration. In the wetter regions of the world, water management involves removing excess water from the soil during and after rainy periods, and reducing evaporation and transpiration losses during dry periods. Drier regions of the world are normally concerned with preserving the water in the soil and adding additional water to the soil as needed by the crop. This is accomplished by some form of irrigation, usually from a limited supply of water. Therefore, water management in drier regions also involves irrigation scheduling. The discussion on soil and water management will be limited to dry land or rainfed conditions.

Management of soil water has generally focused on controlling water lost from the soil by the process 'of evapotranspiration. Only minor attention has been given to the efficiency of getting water into the soil. Most studies of infiltration have been conducted as a part of research dealing with the water runoff and its associated soil erosion. The problem of soil being carried off a slope by water is obvious. An additional problem that occurs when water runs off a slope before it can be absorbed by the soil is that the soil profile remains dry, and the productivity of that sloping land is decreased.

Total water infiltration (W_{in}) into the soil in inches, may be defined as

$$\begin{aligned} P < I_f \rightarrow \quad & W_{in} = P \\ P \geq I_f \rightarrow \quad & W_{in} = I_f \text{ and } W_{off} = P - I_f \end{aligned} \tag{1}$$

where P is the rate of precipitation or water applied to the soil surface in inches/hours, I_f is the infiltration rate in inches/hour, t is the time the water remains on the surface in hours, and W_{off} is the water runoff in inches/hour. Equation 1 limits the amount of water entering the soil in one hour to the infiltration rate. Therefore, the total water entering the soil may be increased by increasing the infiltration rate, increasing the time the water remains on the surface, and/or decreasing the rate of precipitation or water application to a rate that is equal to or less than the infiltration rate. Man has not found a method of controlling the rate of natural rainfall; therefore, to increase total water entering the soil the infiltration rate and time the water is on the soil surface must be managed.

The rate that water enters the soil surface is a function of the surface soil structure. Thus, any tillage operation or management practice that will increase the surface soil structure will speed up the infiltration rate. The major soil constituents that maintain soil structure are clay and organic matter content. Therefore, as organic matter and clay content (to a point) increase, the structure of the soil should improve.

Tillage can be used to improve the infiltration rate when a crust has formed on the soil surface. A hard crust often forms after a heavy rainstorm due to the surface soil structure being broken down by the wetting of the soil clods and the energy of the raindrops. This crust results in emergence problems for young crops and a reduced infiltration rate at the start of the next storm.

The second method of increasing total water infiltration is by increasing the time that water remains on the surface. This may be accomplished by leveling the land. Less expensive management techniques include maintaining residue on the soil surface, any other practice that decreases soil erosion such as maintaining plant growth or plant residue on the soil surface, or building terraces in the field.

With plants growing in the soil, water will be naturally lost through plant transpiration. However, when plants are not growing, the producer should reduce as much soil evaporative loss as possible. This is best done by maintaining a cover of residue on the surface. Tillage tends to dry the soil out, by pulling moist soil to the surface and burying dry surface soil. When this happens, the soil layer from the surface to the depth of tillage tends to dry out. This suggests that by minimizing tillage and maintaining residue on the surface, producers can reduce evaporative losses from the soil.

However, when a residue cover is maintained on the soil surface, the soil will take longer to warm up in the spring than without a cover. Therefore, a producer must weigh the benefits of maintaining soil moisture against allowing the soil to warm up in the spring. It should be noted that dry soils will warm up faster than wet soils. Thus, during a dry spell, the decision may be made to maintain the soil cover to increase the total water infiltration into the soil and sacrifice soil warming in the spring. Conversely, during a wet spell, the best management practice may be to reduce residue cover as much as sound soil conservation practices allow, so that soils which tend to be excessively wet will dry out.

There are also situations where the water table is so close to the surface that the major problem in most years is too much water rather than not enough. Under these conditions, the soil surface layer remains very wet until late in the spring, and planting is delayed. In these situations the water must be carefully removed from the soil. This is normally accomplished by placing a drainage network below the soil surface at an approximate depth of 40 inches. In some instances where water also stands in basins for more than a day, "stand pipes" are installed in the low areas to drain the surface ponds into the drainage system.

In addition to the tendency for slow drainage of water from the soil surface, the need for drainage can be determined using a time series of soil moisture data similar to that presented in figure 2. The time series shows the average annual soil moisture throughout the year. The upper line in each soil layer is the water held by the soil at saturation, and the bottom line is the water held at the wilting point. Notice that in the 42- to 50-inch layer, the soil moisture is near saturation during the spring of the year. This soil is naturally poorly drained soil and the site is drained by field tile. If the field were not drained by field tile, layers above the 42- to 50-inch layer would be saturated during the spring.

Crop Water Requirements

In regions where natural rainfall is limited and water supplies are scarce, the need to understand the water requirements of the crop is obvious. This information may also be used in more moist sub-humid areas to plan rainfed cropping systems to evaluate the effects of water shortages on the crop. This process requires a knowledge of the total water normally available to the plant and the crop water requirements.

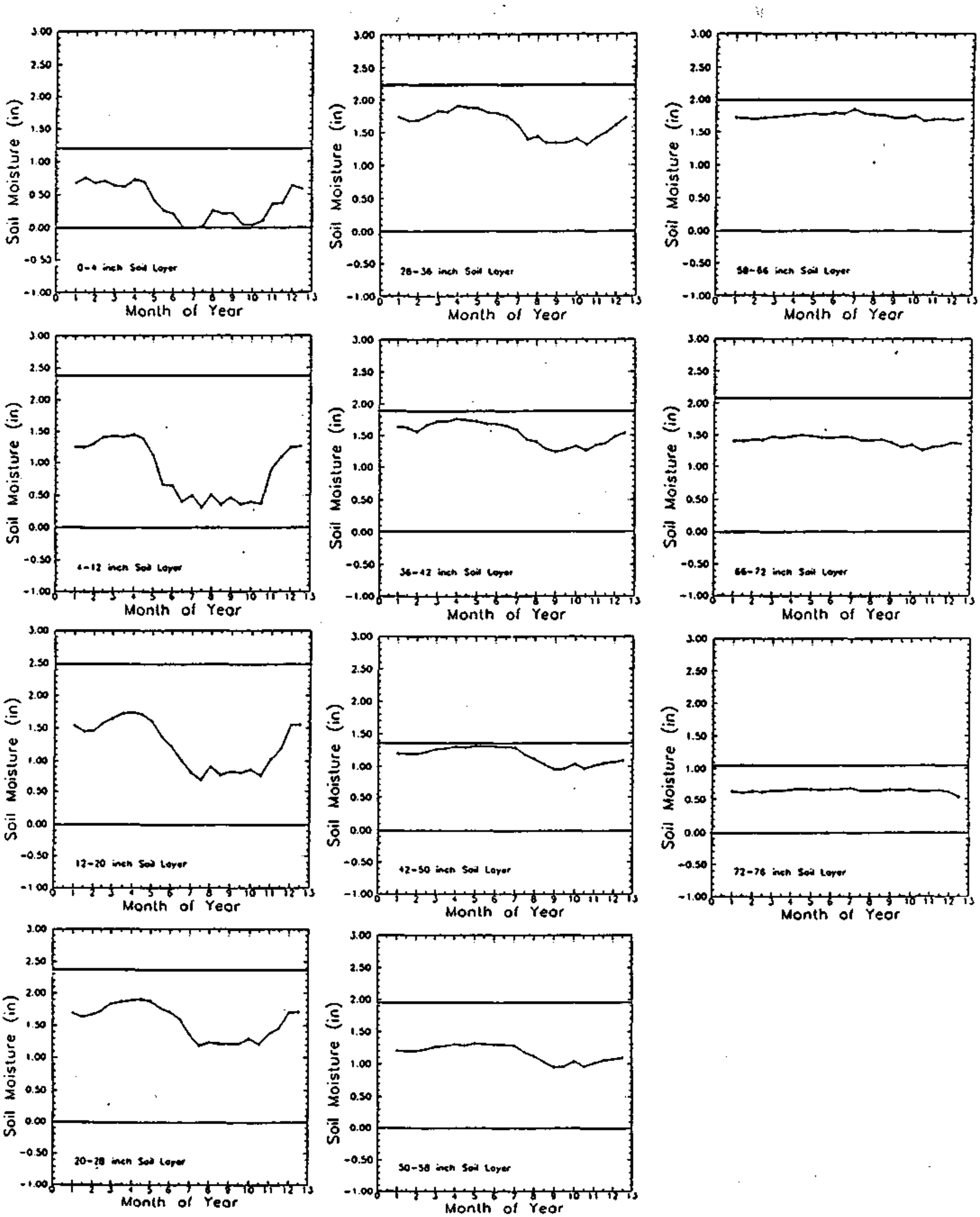


Figure 2. Average soil moisture changes through the year at Champaign, Illinois.

Determining Plant Available Water. The total water available to the plant during a given season is the sum of the water available in the soil at planting, and the water entering the soil from natural rainfall or irrigation. The total amount of water stored in the soil that is potentially available to the crop is a function of the soil water holding capacity and the root depth.

The soil water holding capacity is a function of soil texture and structure. Water is held in the soil against the forces of gravity and root uptake by a natural attraction of the soil colloids to water and the capillary action of pore spaces. The percent of pore space (φ_f) in a volume of soil is dependent upon the bulk density of the soil, and in practice is computed from a determination of bulk density by

$$\varphi_f = 1 - \rho_b/\rho_s \qquad (2)$$

where p_b and p_s are, respectively, the bulk and particle densities of the soil. From equation 2 it can be seen that as the bulk density decreases, the pore space increases. Therefore, as bulk density decreases a larger portion of the soil volume is comprised of pore spaces. If the bulk density becomes too low, a large number of macro-pores will comprise the soil volume, and even though the soil profile will contain more water at saturation, this water will not be available to the crop since it will drain through the soil profile and out of the root zone. Hence, there should be some "optimum" soil bulk density for each crop defined by the ability of the plant roots to penetrate the soil and the potential maximum amount of water available to the plant in the root zone.

When the soil pore space is completely filled with water, the soil is said to be saturated. Unless the water table is at the soil surface, the soil will remain saturated for only short periods of time, because gravity will pull water down to the deeper regions of the soil profile.

The soil is said to reach "field capacity" after it has drained from a state of saturation for 24 hours. Field capacity is used loosely here since there is no good definition of field capacity that applies universally for all soils and soil conditions. The major use of field capacity is to define an upper limit on the water potentially available to the plant in the soil profile. The water between "field capacity" and saturation is normally not available to the plant since it is removed from the root zone before the plant can use it.

The lower limit to plant available water is called the wilting point. At this point the soil colloids hold the water with a tension greater than the tension a plant can apply to remove the water from the soil. The difference between the "field capacity" and the wilting point is called the plant available water, or potentially plant available water, and is expressed as inches of water per inch of soil (in/in).

To determine the total amount of soil water available to the plant at the start of the season, the effective root zone must be known. The maximum potential plant available water (W_{tot}) can be computed by

$$W_{tot} = W_{ppav} \bullet D_r \tag{3}$$

where W_{ppav} is the potential plant available water in (in/in) and D_r is the effective root depth.

In practice the computation of the available water in the root zone requires (1) an estimate of the plant available water in each of the different soil layers, expressed as a percent of the potential plant available water; (2) the depth of the soil layers; and (3) the potential plant available water of each layer. The depth of each soil layer and the potential plant available water of each layer may be obtained from modern soil surveys. The percent of potential plant available water in each layer requires some type of measurement. This measurement may be obtained using gravimetric methods, gypsum blocks, tensiometers, neutron probes, or other suitable soil moisture measurement techniques.

Crop Water Requirements. Since most cultivated crops are planted each year, the root zone varies from the planting depth to the effective soil root zone or the maximum depth of the normal root growth for the crop, whichever is more restricting. Therefore, the root growth habits of the crop must be known, along with the amount of water needed as a function of crop growth stage.

To plan a water management plan for a given situation, the time of each crop growth stage must be estimated. A simple and commonly used method of doing this is counting the number of days after planting. However, for most crops the greatest water demand and the most critical stages for water are during flowering and early grain set. Using the number of days since planting or emergence results in large errors in the time of these critical stages. (The discussion in this paper is restricted to the grain crops of corn, soybean, sorghum, and wheat.) The errors are due to the differences in temperature from year-to-year.

The development of most crops is dependent upon the temperature experienced and the photoperiod, if the crop is photoperiod sensitive. Therefore, with crops that are only temperature sensitive, a better method of predicting crop development is the computation and accumulation of "growing degree units." The general equation for computing growing degree units (G_u) is

$$G_u = [T_{mx} + T_{mn})/2] - T_b \tag{4}$$

where T_{mx} and T_{mn} are the maximum and minimum daily temperatures, respectively, and T_b is a base temperature. If G_u is less than 0, G_u is set equal to 0. This prevents the accumulation of negative G_u's, which would imply a reversal of crop development, an impossible condition.

The base temperature of wheat is 40° F, and the base temperature of corn and sorghum is 50°F. The base temperature is the temperature below which crop development is assumed to stop. For many crops there is a maximum temperature above which the rate of crop development is reduced. Therefore, a modified growing degree unit (G_{mu}) has been devised that is used for the warm season crops of corn and sorghum. The computation of G_{mu} is the same as equation 4 with the exception that if T_{mn} is less than 50 ° F, T_{mn} is set to 50°F, and if T_{mx} is greater than 86°F, T_{mx} is set equal to 86°F. Tables 2, 3, and 4 present the growth stages along with the corresponding root depths, daily water use requirements, and the relative growing degree units required to reach each stage. Relative growing degree units are the ratio of the growing degree units necessary to reach a given growth stage, and the growing degree units necessary for the crop to reach maturity.

The soybean varieties grown in the central United States are very photoperiod sensitive. To estimate the start of flowering, a photoperiod function must be used. There are various soybean phenology models in the literature (Hodges and French, 1985; Jones and Laing, 1978; Wang, et al., 1987) that include both growing degree units and photoperiod in estimating soybean development.

For this paper and the growth stage determination used in Table 5, the procedure used by Wang et al. (1987) has been adapted to estimate development as number of days after planting. The data in Table 5 represent approximate days after planting at a latitude of 40° north. The approximate days for different latitudes may be determined by computing the photoperiod at the longest day of the year (June 21 in the northern hemisphere) using

$$D_1 = 2\{\cos^{-1} [-\tan\delta \bullet \tan\Phi]\}/15 \tag{5}$$

where D_1 is the day length in hours, 5 is the solar declination on the longest day of the year (23.45 °), and Φ is the latitude. The number of days from planting to maturity (D_{pm}), and planting to flowering (D_{fl}) are computed by

$$\begin{matrix} D_{fl} \\ D_{pm} \end{matrix} = a + (b \cdot 10^{-6}) [\exp(D_1)] \tag{6}$$

where a and b are the coefficients given in Table 6 for soybean groups II, IV, and V. Following the sequence of soybean stage development described in <u>How a Soybean</u>

Develops (Iowa State University, Special Report No. 53), it is assumed that 5 days elapse between each vegetative stage up to V5. The relative time span between reproductive stages is computed as the ratio of the length of the reproductive period computed by

$$D_{ri} = D_i \cdot (D_{pm} - D_{fl})/72 \tag{7}$$

where D_{ri} is the days from stage R1 to stage Ri (i = 1 to 8), and D_i is the days from R1 to stage Ri given in the How a Soybean Develops and reproduced in Table 5.

Table 2. Corn growth stages, relative growing degree units to each stage, estimated rooting depth, and estimated water use during each growth stage. (Adapted from Aceves-Navarro, 1987; Teare and Peet, 1983.)

Growth Stage	Relative Growing Units	Root Depth (in)	Water Requirement (in/day)
Planting	0.00	2.00	0.06
2-Leaf	8.00	5.00	0.08
4-Leaf	14.00	6.00	0.11
6-Leaf	17.00	8.00	0.13
8-Leaf	23.00	12.00	0.15
10-Leaf	32.00	16.00	0.18
12-Leaf	38.00	20.00	0.20
14-Leaf	43.00	24.00	0.23
Silk	50.00	36.00	0.30
Anthesis	52.00	38.00	0.30
Blister	62.00	40.00	0.27
Dough	72.00	42.00	0.25
Early Dent	81.00	42.00	0.15
Full Dent	91.00	42.00	0.10
Mature	100.00	48.00	0.07

Table 3. Sorghum growth stages, relative growing degree units to each stage, estimated rooting depth, and estimated water use during each growth stage. (Adapted from Aceves-Navarro, 1987; Teare and Peet, 1983.)

Growth Stage	Relative Growing Units	Root Depth (in)	Water Requirement (in/day)
Planting	0.00	2.00	0.06
3-Leaf	10.00	6.00	0.07
5-Leaf	22.00	10.00	0.09
Panicle In	33.00	15.00	0.13
Final Leaf	44.00	30.00	0.18
Boot	55.00	36.00	0.23
50% Bloom	66.00	42.00	0.28
Soft Dough	78.00	46.00	0.25
Hard Dough	89.00	48.00	0.18
Mature	100.00	48.00	0.12

Table 4. Wheat growth stages, relative growing degree units to each stage, estimated rooting depth, and estimated water use during each growth stage. (Adapted from Aceves-Navarro, 1987; Teare and Peet, 1983.)

Growth Stage	Relative Growing Units	Root Depth (in)	Water Requirement (in/day)
Init SprG	0.00	6.00	0.01
Leaf Elong	7.00	12.00	0.03
Joint	19.00	18.00	0.16
Boot	30.00	24.00	0.22
Head	42.00	36.00	0.27
Flower	53.00	36.00	0.32
Grain Fill	65.00	36.00	0.35
Dough	77.00	36.00	0.32
Ripening	88.00	36.00	0.20
Mature	100.00	42.00	0.05

Table 5. Soybean growth stages, relative growing degree units to each stage, estimated rooting depth, and estimated water use during each growth stage. (Adapted from Aceves-Navarro, 1987; Teare and Peet, 1983.)					
Growth Stage	Days from Planting to Growth Stage			Root Depth (in)	Water Requirement (in/day)
	Group III	Group IV	Group V		
Planting	0	0	0	2.00	0.05
V1	10	10	10	4.00	0.06
V3	18	19	24	10.00	0.08
V5	26	27	38	15.00	0.11
R1	34	35	52	20.00	0.14
R4	53	56	73	25.00	0.19
R5	61	64	81	30.00	0.25
R6	73	78	95	30.00	0.31
R7	88	94	110	30.00	0.32
Mature	97	103	120	30.00	0.23

Table 6. Coefficients for computing the days required for soybeans to go from planting to maturity (D_{pm}) and from planting to flowering (D_{fl}).				
Soybean			Coefficients	
Maturity Group	Planting to Flowering		Planting to Maturity	
	a	b	a	b
III	26	2.8	83	5.1
IV	26	3.3	87	5.6
V	25	9.7	97	8.3

Table 7. Range of heat units from January 1 to a given European Corn Borer life stages.	
European Corn Borer Growth Stage	Base 50 Heat Units
First Generation	
Adult Emergence and Flight	432 to 911
Eggs	650 to 1030
First instar larvae	844 to 1122
Second instar larvae	969 to 1247
Third instar larvae	1139 to 1417
Fourth instar larvae	1287 to 1567
Fifth instar larvae	1417 to 1695
Pupae	1520 to 1798
Second Generation	
Adult Emergence	1620 to 1898
Moth Flight and egg laying	1748 to 2513
First instar larvae	1901 to 2636
Second instar larvae	2021 to 2756
Third instar larvae	2109 to 2844
Fourth instar larvae	2210 to 2945
Fifth instar larvae	2323 to 3058

Examples of Climate and Weather Use in Agriculture

Nitrogen Management. An increasing concern in rural communities is the rising levels of nitrates in the water supply. Additionally, the products of denitrification, specifically N_2O, are contributors to greenhouse gases and thus a concern relative to global change. Therefore, any procedure that will improve the efficiency of nitrogen fertilization will preserve the environment and improve producers' profits. Weather plays an important role in the efficient use of nitrogen fertilizers. The important weather variables in this case are precipitation and temperature, specifically soil temperature.

Hollinger and Hoeft (1986) studied the response of corn to NH_3 application as it was affected by weather. The expected relative yield (Y_E) of corn to additional increments of NH_3 was defined by

$$Y_E = \alpha(N+1)^{\beta} \tag{8}$$

where α is the relative yield if no NH_3 is applied, and β is the increase in yield with each additional increment of NH_3. α and β were found to be highly related to the ratio of the precipitation to evaporation between the periods of June 11 to July 5, the normal time of rapid corn growth at the location of the study. Equations 9 and 10 define α and β, respectively,

$$\alpha = 1.980 - 5.266\,(P/E) + 4.231(P/E)^2 \tag{9}$$

$$\beta = -0.422 + 1.987(P/E) - 1.621(P/E)^2 \tag{10}$$

where P is the total precipitation, and E is the total pan evaporation from June 11 to July 15. Figure 3 shows the relationship between P/E and α and β. The optimum P/E is approximately 0.6. Below 0.6 precipitation becomes limiting, and above 0.6 the soils are wet enough that nitrogen is lost through leaching of NO_3 after nitrification and also through denitrification.

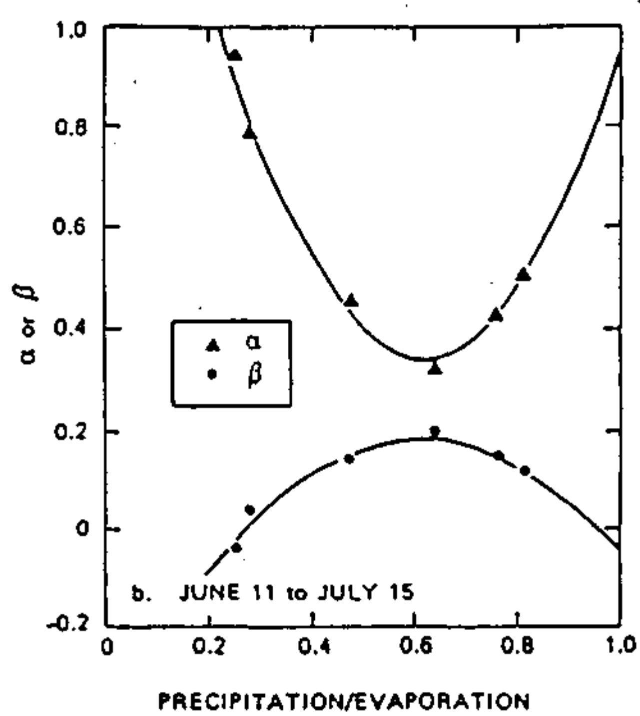


Figure 3. Relationship between precipitation/evaporation and the relative maximum yield (a), and corn response to NH_3. (Adapted from Hollinger and Hoeft, 1986).

Additional research by Hoeft et al. (1986), showed significant levels of NO_3 nitrogen could be lost if the soil neared saturation several days following NO_3 application. The loss was greatest on heavy silty clay loam soil with high organic matter content. Additional studies by Torbert (1989) indicate that this loss is due mainly to denitrification.

The two studies mentioned above demonstrate that the use of climate and weather information in making nitrogen management decisions should improve the efficiency of nitrogen use.

Insect Management. Many producers expend a considerable amount of time and money to control crop insect pests. The most common procedure for controlling pests is with applications of chemical pesticides. These chemicals are expensive and experience shows that in addition to being a hazard to the environment, as their use continues they become less and less effective. Therefore, procedures need to be developed that will reduce the need for insect treatments. Weather and climate information can be used to improve the timeliness and the effectiveness of a chemical application. This is especially true when the system approach is used where the crop susceptibility and insect development and population is considered.

Figure 4 is a plot of the rate of modified base 50 growing degree unit (eq. 4) accumulation for corn, and the probable time of European Corn Borer (ECB) appearance based on the accumulation of heat units from January 1 (Table 7).

Several methods have been proposed for computing heat units for insects. One approach is to duplicate the crop method (eq. 4). The other assumes a sine function as the temperature approaches the upper and lower temperature threshold. This approach attempts to account for the non-linear change in metabolic rates at temperature extremes.

With the last method, if the minimum temperature is above the base temperature, the procedure is the same as the GDU_{50}. If, however, the minimum temperature is below the base temperature, the mean daily temperature (T_A) is computed as

$$T_A = (T_{mx} + T_{mn})/2 \bullet \tag{11}$$

An angle (Θ) is computed as

$$\Theta = Sin^{-1} ((T_B - T_A) / (T_{mx} - T_A)) \tag{12}$$

where T_B is the base temperature. Finally, the daily heat unit accumulation (HU) is computed by

$$HU = (((T_A - T_B)(\pi/2 - \Theta)) + ((T_{mx} - T_A) Cos\ \Theta))/\pi \quad (13)$$

The objective of figure 4 is to provide a method to determine if there is planting date-hybrid combination that will de-synchronize the time when the pest is present and the crop is susceptible to damage. If such a combination exists, the number of chemical treatments can be reduced. This is an example of strategic planning.

As an example, the corn crop is most susceptible to ECB damage between the 10 leaf growth stage and early dent (Lynch, 1980). The typical ECB life cycle stages in figure 4 are the "normal" dates for Urbana, Illinois. From Table 2 the corn growth stages with relative growing degree days required to reach each stage can be obtained. To find the absolute growing degree days to reach a given stage, divide the value for the desired stage from Table 3 by 100 and multiply by the growing degree units required by the selected hybrid to reach maturity.

Since the rate of heat unit accumulation is different each year, the final tactical season plan is arrived at by observing the accumulation of heat units in a given season and then using the climatology of heat unit accumulation to "forecast" the likely time of ECB appearance. Once this is known, target planting dates can be looked at with different hybrid maturities to select the optimum hybrid for the season.

Climate data may also be used to track insect development during a year. The procedure is to accumulate the insect heat units from the first of January until the present time; then, use climatology to project the probable date of the insect appearance. Such a procedure can assist in the day-to-day planning of when to begin scouting for a given insect. The procedure should not be used to determine when to treat for the insect. This can only be done after the field has been scouted and the insect population has been established and an estimate of probable damage to the crop has been made.

Hybrid/Variety Selection. The example given for insect management is one case where weather may be used to select a hybrid. Other examples include selecting a planting date-hybrid combination that will reduce the risk of the crop being in a critical growth stage when there is a high probability of unfavorable weather (i.e., corn pollination during the hottest week of the year). Realistically, it is impossible to predict the hottest and/or driest week of the year. However, a study of the climate record provides the means of determining the risk involved for each week of the growing season.

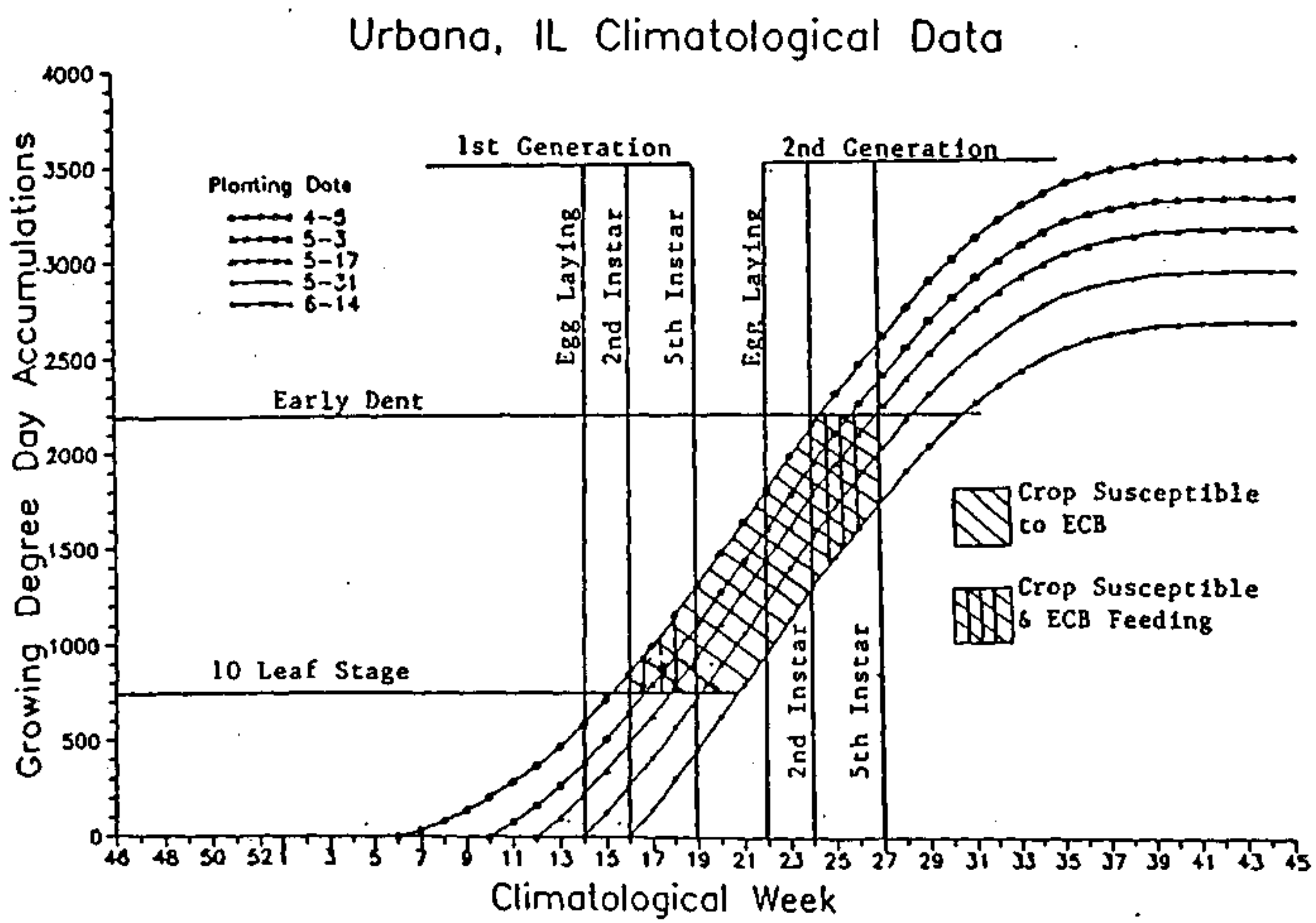


Figure 4. Growing degree day accumulation from different dates of planting and the normal dates of different European Corn Borer stages at Urbana, Illinois. Degree day accumulations are computed from the 1901 to 1988 climate record.

Two examples could be discussed in this section 1) the probability of a heat stress during corn pollination, and 2) the probability of a water stress during corn pollination. We will discuss the first example here.

Figure 5 is a plot of the normal growing degree day accumulations for different planting days, along with the frost and heat stress probabilities for each climatological week of the year. The planting dates begin the first week of April and end the week of the 15th of June. The frost probabilities are based on a 32 ° F temperature, and the probability of a heat stress is based on the maximum temperature exceeding 86°F during the week.

Using the data in Table 2, the date of any growth stage can be estimated and the probability of a heat stress occurring during that period determined. For example, for a corn hybrid requiring 2700 GDU (Growing Degree Units) to reach maturity, silking occurs when 1350 GDU have accumulated from the date of planting. Assuming the planting date was on May 3, the crop is predicted to silk during the week of July 19 and mature during the week of September 20. There is a 49% chance of a maximum temperature greater than 86 ° F occurring during the week of July 19; therefore, the crop is likely to experience at least a mild heat stress. The crop should mature before any frost occurs. If planting were delayed to the week of May 31, this hybrid would mature during the week of October 11 with a 10% chance that frost would have occurred prior to the crop maturing.

The above example indicates how figure 5 can be used to accomplish strategic and seasonal tactical planning. The results indicate the "normal" situation. However, each year will differ and actual growth stage dates will vary, depending upon the temperature during the year.

SUMMARY

Weather and climate play an important role in the success of modern-day agriculture. However, the general feeling is we cannot do anything about the weather. While we cannot change the weather and the long-term climate, we can use the climate and weather information to "weather proof production agriculture. Weather proofing agriculture requires a knowledge of the climate, the soils of the farm, the life cycles of the insects, and the environmental physiology of the crops that were being grown or might be grown in a given area.

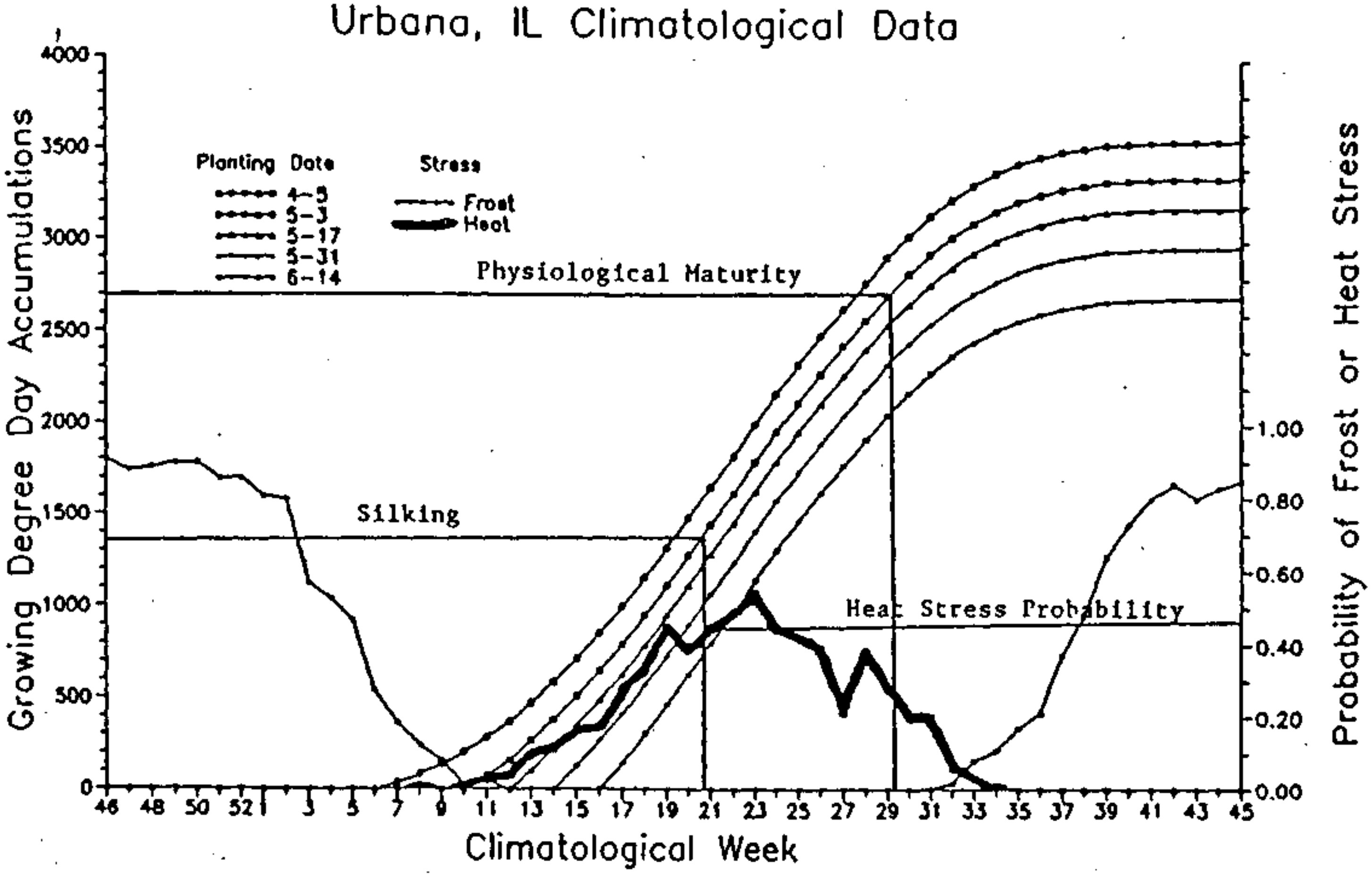


Figure 5. Growing degree day accumulation from different dates of planting and the probability of a frost and/or a heat stress during each climatological week.

Researchers and production consultants need to continue to search for the response of production agriculture to weather. This does not require establishing additional multi-year experiments since there is a wealth of this type of experimental data. The existing data should be reexamined to determine what weather factors contributed to the year-to-year variation in the data. Diligent attention to this year-to-year variability and the associated weather will help create the next "green revolution." This revolution will not come from the fields of biotechnology or genetic engineering, but from the optimization of current production practices as they are affected by the weather of an area. The methods presented above serve as an introduction to the use of weather and climate information to help analyze a particular operation and improve production efficiency.

ACKNOWLEDGEMENTS

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A MID-SEASON CLIMATOLOGY OF JET CONDENSATION TRAILS FROM HIGH RESOLUTION SATELLITE DATA

by
James Q. DeGrand,[1] Andrew M. Carleton,[1] and Peter J. Lamb[2]

INTRODUCTION

Recent investigations of cloud cover over North America document an upward trend in cloud amount (Angell and Korshover, 1984; Changnon, 1981; Henderson-Sellers, 1989) and a decrease in the number of cloudless days (Seaver and Lee, 1987). The difference in the magnitude of the changes in cloudiness and sunshine suggests that the cloud increase may be due to thin cirrus (Angell and Korshover, 1984). There is speculation that these changes are due, at least in part, to anthropogenerated clouds in the form of jet condensation trails (contrails). The potential for contrails to influence climate has been much debated. The reason for the continuing uncertainty is, first, the influence of cirrus clouds, particularly thin cirrus (e.g., contrails) on the earth's radiation budget is not yet well understood (Liou, 1986). Second, while there have been several studies of the incidence of contrails (Detwiler and Pratt, 1984; Changnon et al., 1980; Wendland and Semonin, 1982), contrail climatologies covering extensive geographic areas and having high temporal resolution have not yet been produced, thus precluding the inyestigation of the climatic effect of contrails. Carleton and Lamb (1986) showed the feasibility of using Defense Meteorological Satellite Program (DMSP) imagery to derive such a climatology. They concluded that the DMSP imagery was well suited for an investigation of contrails due to its high spatial (0.6 km) and temporal (potentially 4 times daily) resolution. We here present some preliminary results from an investigation of contrail formation over that part of North America and the Atlantic and Pacific Oceans from 20° to 60° north, and from 65° and 150° west (here called the study area), based on DMSP imagery.

DATA AND ANALYSIS

Visible and infrared images from the polar-orbiting DMSP satellites archived at the World Data Center A for Glaciology (Snow and Ice), Boulder, Colorado, were used to

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identify contrails over the study area. Direct read-out images from Patrick Air Force Base (Florida) and San Diego Naval Base (California) provided coverage over the entire study area and were analyzed for mid-season months (January, April, July, and October) for three years (1977-79). There were no data for January, 1977. This time period was chosen because data from both stations were abundant relative to earlier and later periods. The high spatial resolution (0.6 km) of this imagery was capable of resolving features on scales typical of the more persistent contrails. The infrared imagery allowed for distinctions to be made between low and high cloud.

Contrails were identified as linear, bright (i.e., high), generally short features often having orientations different from the surrounding clouds (Carleton and Lamb, 1986). Each contrail was geolocated in reference to a 1° x 1° grid covering the study area. The frequency of contrails over the study area was determined for each gridcell for each mid-season month and for each of four six-hour time periods (00-06 GMT; 06-12 GMT; 12-18 GMT; 18-00 GMT).

DISCUSSION

The spatial distribution of monthly mean contrail frequencies (Fig. 1) indicates that contrail formation is widespread over the United States and southern Canada. However, the distribution is not uniform. Areas in which contrails formed frequently are the U.S. Midwest and Southwest, and western British Columbia. The area north of Los Angeles seems particularly favored for contrail formation. The raw frequencies are low considering the volume of air traffic over the study area and the number of contrails that have been observed from the ground (Wendland and Semonin, 1982). These low frequencies are due in part to the stringent criteria used in identifying contrails (see above). This method effectively precludes the identification of contrails which have been significantly altered in shape by upper level winds. Higher frequencies would likely be observed using the methodology outlined by Lee (1989), which identifies contrails based on brightness temperature differences in the AVHRR infrared split window. The lack of data in the 18-00 GMT time period during which air traffic is heavy (afternoon on the East Coast, mid-day on the West Coast) also reduces the total number of contrails identified.

Some of the variability in raw contrail frequencies is due to variations in the number and areal coverage of the imagery from the two stations. The effect of these variations on contrail frequencies is estimated by fitting the following model:

$$C(n) = b_0 + b_1 I(n) + b_2 A(n)$$

where:

$C(n)$ = predicted frequency of contrails for month n,

$I(n)$ = number of images for month n,

$A(n)$ = mean area of the images for month n,

b_0, b_1, b_2 = parameters to be estimated.

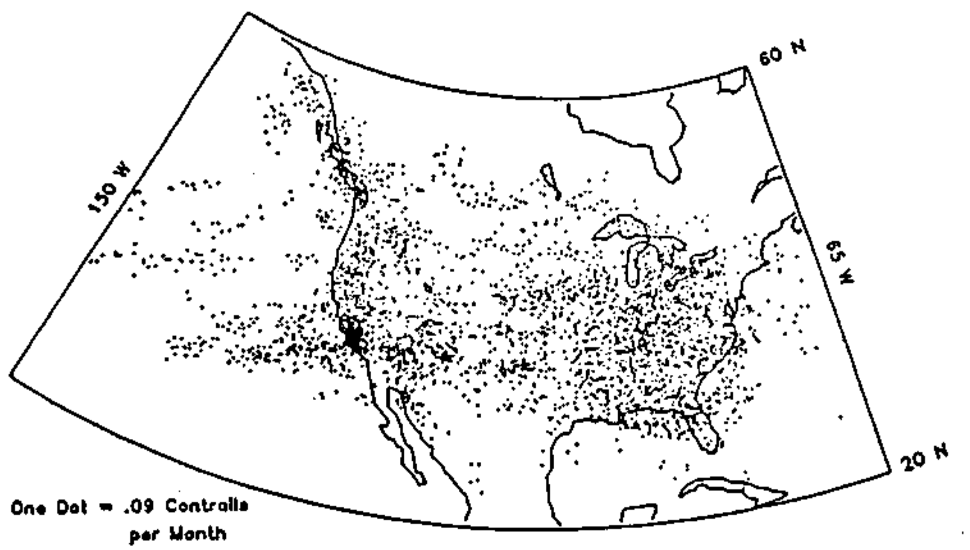

Fig. 1. Monthly Mean Frequencies of Contrails per 1° x 1° Gridcell

Table 1 summarizes the results of the regression analysis. The variability of the departures of the observed from the expected contrail frequencies may be considered to be representative of the combined effects of variations in air traffic in the upper troposphere and changing meteorological conditions. The distribution of the departures from expected frequencies for each gridcell did not differ significantly from the distribution of the raw frequencies shown in Figure 1. The relative absence of contrails in the areas known to have high volumes of air traffic (e.g., the Northeast U.S.) and the high frequencies over areas with lower volumes of air traffic (e.g., the Northwest U.S.) indicate that meteorological conditions play a critical role in determining the seasonal and geographic distributions of contrails. It would be possible to fully decouple the effects of air traffic and meteorological conditions given a dataset of the number of air carrier flights between North American cities on a monthly (or shorter) basis. At this time however, we have been unable to locate such a dataset.

Table 1. Ordinary least squares results for regression of contrails on number and area of images analyzed.			
Parameter	Estimate	Student's t-statistic	probability > |t| by chance
b_0	-132.218	-3.41	0.0016
b_1	5.542	9.95	0.0001
b_2	1.732	2.95	0.0056

Assuming that there are no profound changes in air traffic from season to season, the mean seasonal departures form expected contrail frequencies represent the seasonal departures from expected contrail frequencies represent the seasonal variation in contrail formation due to changing meteorological conditions. Table 2 summarizes these departures. They indicate that the fall and summer are, respectively, the seasons having the largest and smallest number of contrails. This seasonal variability is likely to be associated with changes in tropopause height, temperature, lapse rate and mixing ratio, and is the subject of continuing research using the contrails database.

Table 2. Monthly mean departures from expected frequencies (Obs - Exp).			
Jan	Apr	Jul	Oct
3.892	-0.000	-23.504	20.910

The diurnal variation in contrail frequency was determined by calculating mean departures from the predicted frequencies for each of four 6-hour time periods (Table 3). The diurnal variability of the departures from expected contrail frequencies indicates that contrails form most frequently during the 1800-0000 GMT time period, and least frequently during the 0600-1200 GMT time period. Since there is little diurnal variability in upper tropospheric temperature and relative humidity, it is reasonable to associate the diurnal contrail variability with variation in air traffic. This is supported by the fact that the 1800-0000 (0600-1200) time period corresponds to periods with air traffic is likely to be heavy (light) over the study region.

Table 3. Mean departures (Obs - Exp) for four 6-hour time periods.			
00-06	06-12	12-18	18-00
27.955	-44.019	-7.472	23.537

CONCLUSIONS

This study demonstrates that contrails are a widespread phenomenon over North America, particularly over the U.S. While the geographic distribution of contrails is broadly similar to published generalizations of air traffic over the U.S. (U.S. Geological Survey, 1970), there are significant departures from this pattern in some regions. There is also a seasonal variation in contrail formation. Ongoing research seeks to establish the meteorological conditions which give rise to these spatial and temporal variations.

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IMPACTS AND SOME LESSONS TAUGHT BY THE 1988 DROUGHT[1]

by
Stanley A. Changnon, Jr.[2]

ABSTRACT

One of the worst droughts of the 20th Century peaked in the contiguous United States during 1988. Its impacts were pervasive, affecting agriculture, water resources, transportation, recreation, and wildlife. Costs and losses amount to nearly $40 billion, making it the worst natural hazard of this Century. Governmental responses were typically made in a crisis mode, reflecting poor preparation and lack of planning. The drought impacts and responses suggest several actions are needed at the federal level to address future droughts including a standing interagency task force, updated water management plans, development of drought contingency plans where none exist, and improvements in the system for predicting, detecting, and monitoring drought at the local, regional, and national scales.

INTRODUCTION

The physical, social and economic impacts of the drought, which started in 1987 and reached a peak severity in the summer of 1988, were ubiquitous, pervasive, and will reverberate through the U.S. environment and economy for some time to come. The drought pointedly reminded scientists, the public, and policymakers how sensitive environmental and socio-economic systems are to a simple hazard: lack of normal rainfall and above normal temperatures. Major impacts occurred in agriculture, water resources, transportation, recreation/tourism, wildlife and other elements of the country's environmental and economic infrastructure, though, of course, losses in some areas were balanced by gains in others.

The President's Interagency Drought Policy Committee (1988) estimated that the total drought losses in agriculture alone during the last three-quarters of 1988 were $13 billion of direct GNP. Second- and third-quarter GNP growth was reduced to 0.9% and 0.6%, respectively, due mostly to reduced agricultural production. This increased retail food prices

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[1]From Planning for Water Shortages, U.S. Commission on Irrigation and Drainage, 1989.

[2]Principal Scientist and Chief Emeritus, Illinois State Water Survey, Champaign, Illinois

in the U.S. by 0.5%. In combination with impacts on energy, water, ecosystems, and other aspects of the economy, the drought cost the U.S. roughly $40 billion, making it the most costly natural disaster ever to affect the nation.

IMPACTS

Because of the great extent and intensity of the drought, all aspects of our environment and society were affected. The greatest economic loss was in agriculture, where more than $15 billion in crop losses occurred. There were 20 to 50% reductions in corn, soybean, and spring wheat production. The high value specialty crops of the east and west coasts were also detrimentally affected: Maryland experienced $300 million losses to high value crops. The full dimension of the impacts on agriculture will never be fully assessed, though we know of impacts on seed development, continuing effects on the livestock industry, and a slow trailing off of effects on the consumer due to food price increases. Crop prices soared in 1988, but major grain surpluses accumulated from prior years saved the nation from any form of shortages in 1988-89.

The summer 1988 heat wave was extensive with summer temperatures rated as the highest on record over 13% of the nation, including the major metropolitan areas of the Midwest and Northeast. The result was an estimated 5,000 to 10,000 deaths related to heat stress (Avery, 1988), though the wide range of this estimate testifies to how poorly this critical effect is monitored.

The environment was notably affected with major reductions in water supplies and diminished water quality in streams and wetlands. Forest fire damage in the West was the greatest on record, and the populations of certain species of wildlife in the Mississippi River Basin were reduced from 5 to 30%. The environmental effects will be the most long-lasting of all the effects of the drought of 1988; and there are few, if any, winners from the environmental losses.

Transportation was also uniquely affected by the drought in the central United States. Rapidly falling river levels in the Mississippi River Basin led to stoppages of barge traffic in June and July, with 50% reductions in barge shipments throughout the summer. This caused shipping disruptions and price increases for the shipment of bulk commodities such as coal, grains, and petroleum products.

The drought in the central U.S. was sufficiently short-lived that effects on urban-industrial water supplies in the Midwest were mostly minor. However, it was the second year of a growing water supply drought in the Pacific Northwest, and the fourth year of a continuing drought in the southeastern U.S.; both areas experienced serious water supply problems.

A fifth major area of effect was to the government operations. Local, state, and federal government agencies were affected by the need for added services, and requests for funds and for technical assistance. Governmental responses included the $4 billion in drought relief to relieve the most serious losses to farmers and, in turn, to agribusiness, plus $3 billion in insurance payments. Governments also dealt with a myriad of drought-induced controversies including those relating to the management of forest fires in the West, and the proposed diversion of waters from the Great Lakes to enhance flow of the Mississippi River.

As in all droughts, there were economic "winners." The drought did not embrace the entire nation and farmers growing grain and specialty crops in non-drought areas (the Deep South, southern Great Plains, and the Southwest) achieved higher profits as prices rose. Railroads in the Midwest recorded major profits due to the diversion of shipments from the river systems. In the water supply area, well drillers received much more demand for their service as rural and small urban water system managers came to realize how vulnerable they were. However, though one cannot estimate with any confidence the proportion of the $39 billion total losses that were compensated, the winnings are believed to be small relative to the losses.

Types of Impacts

The values (dollar and otherwise) presented here are estimates and are not derived from in-depth economic or environmental analyses. One must recognize that in many instances, these values are imprecise and subject to errors of unknown sizes.

The drought effects were pervasive and had some form of influence on all U.S. citizens by the end of 1988. In some instances the influences were large, such as among Midwestern and northern Great Plains farmers, and in others they were small, especially on people whose livelihood is not closely associated with natural resources supply. Regardless, the drought broadly affected elements of everyday life such as food prices, which touched everyone from school children to elderly retired persons living in places where the drought did not occur.

Table 1 itemizes many of the drought impacts identified, illustrating the wide diversity of its effects. The sectors most impacted were agriculture, human health, and the environment. Agriculture was especially impacted because the intensity and areal extent of the drought was greatest during the growing season of most primary crops, May-August.

Table 1. Roster of Drought Impacts	
A. Environmental	
1.	Wildlife - reduced populations, food loss for migration
2.	Insects - populations greatly changed, some increased
3.	Forests - major losses; fires, growth stunted, delayed death
4.	Ornamentals - worse than realized to trees and bushes, delayed death
5.	Fish - major losses in low streams, and poor quality
6.	Soil - increased wind erosion
7.	Water - quality very poor, unable to handle industrial discharges and agricultural pollution
B. Human Health (physical and mental)	
1.	Deaths - number of persons totally or partially attributed to heat is in thousands
2.	Illness - asthma, heat stress, etc.
3.	Emotional problems - anxiety over heat stress, loss of income, higher costs for cooling and ornamental treatments, loss of recreational opportunities, concern over climate change
C. Agriculture	
1.	Surpluses reduced
2.	Prices up for corn, soybeans, and wheat
3.	National vs. regional impacts varied
4.	Fanners in drought areas hurt, those elsewhere helped economically
5.	Long-term impacts difficult to assess due to subsidies for exports and production
6.	Showed inability to accurately estimate magnitude of losses during drought
7.	Means to adjust to continuing drought available

8.	Commercial forestry and inland fisheries hurt
9.	Increased crop insects and enhanced spraying
	D. Transportation
1.	Rivers - barge traffic hurt
2.	Railroads - enhanced
3.	Great Lakes - shipping increased
4.	Airlines - fewer weather delays
	E. Power Generation
1.	Record consumption of electrical power
2.	Hydropower generation reduced, costly fossil fuel required
3.	Brownouts, damaged electrical equipment, discomfort to humans
4.	Increased income to power companies
	F. Commerce and Industry
1.	Rain insurance hoax
2.	All-weather peril insurance overwhelmed
3.	Recreation industry - hurt, less revenue
4.	Construction - fewer delays
5..	Shippers - higher costs
	G. Urban Areas
1.	Reduced water supplies
2.	Deaths of elderly citizens due to heat
3.	Inexperience in dealing with drought and choosing of proper responses
4.	Increased water consumption
5.	Developed conservation procedures and penalities

	Water Resources
1.	Low streamflows
2.	Lowered Great Lakes, reservoirs, and farm ponds
3.	Lowered groundwater levels
4.	New sources developed - wells drilled, piping for diversions
5.	Increased public awareness of water value and need for conservation
6.	Increased costs for water and sewage treatment
7.	Interstate conflict heightened
Education	
1.	School hours reduced by heat
Government Issues	
1.	Conflicts between states, especially over water
2.	Establishment of drought task forces
3.	Increased services and costs to government: river channeling, fire fighting, relief payments, etc.
4.	Concern over CO_2 as cause of drought
5.	Effect on election and efforts of new Administration
6.	Need for national attention and planning for future droughts
7.	New legislation for drought relief

Table 2 itemizes some of the sectors and activities that benefitted from the drought. The role of countervailing benefits is best illustrated in agriculture. The USDA estimated that the net agricultural income in the U.S. in 1988 would be $57 billion, almost exactly the total income received in 1987. This fact, despite crop losses of about $15 billion, reflects three general factors. First, producers of specialty crop, corn, soybeans, wheat, and cotton in areas that escaped the drought (portions of the South, southern Great Plains, and Southwest) had average to above average yields. With increased prices, they experienced major income gains. Second, some farmers, and most grain companies in the drought areas, sold surpluses acquired from 1987 and 1986 at 1988's higher prices, helping to ameliorate their physical crop losses. Farmers with irrigation in drought regions also were able to sustain high yields and were also beneficiaries of increased commodity prices.

. Table 2. Roster of Winners from Drought Conditions	
1.	Agricultural producers in non-drought areas and those with large surplus stocks
2.	Railroads
3.	Water-producing technologies (well drillers, weather modification companies, evaporation suppressants)
4.	Electric utilities (increased power sales)
5.	Coal companies (increased sales from greater use of coal at coal-fired utilities)
6.	Great Lakes ports (+15% increase in shipping)
7.	Construction Industry (increased profits due to fewer rain stoppages)
8.	Commercial Aviation (increased profits with fewer weather delays)

Railroads in the Midwest benefitted because of the reduced shipment of bulk commodity goods on the Mississippi River system. Low flows from June through the fall of 1988 reduced barge shipment by 50%, producing an increase of barge prices, with the net result of increased shipments of coal, petroleum products, and grains on the railroads of the central United States.

The estimated additional income of the railroads in this area was $200 million.

Those dealing in "water technologies" were also beneficiaries. This included well drillers, companies providing weather modification services, and companies providing chemicals for evaporation suppression.

The electrical utility sector experienced general income increases due to the record high temperatures during July-August, which increased sales of power for air conditioning. Coal-fired utilities realized further profits as the generation of hydroelectric power was reduced by low river flows, and hydroelectric-based utilities were forced to purchase power from the coal-based utilities. This led to another winner, the coal companies, which had increased sales.

Another beneficiary was the Great Lakes ports and shippers. The diversion of grain and commodities export grain shipments to the railroads led to increased movement of these grains through Great Lakes ports with the corresponding decrease in shipping from Gulf ports. In general, all weather events of consequence produce winners as well as losers, but the net effect of an event like the drought is likely to be negative, given the physical damages and transaction costs of alternatives.

RESPONSE TYPE PROBLEMS AND LESSONS LEARNED

Analysis of the drought impacts revealed a series of major problems relating to reactions and responses. The first of these related to the slow detection of the drought with inadequate monitoring until it was well defined, and poor interpretation of the drought severity. The second problem area was related to the lack of information as to management options available to decisionmakers. In the agricultural sector there was confusion over the use of agricultural relief versus crop insurance to deal with agricultural losses. Another noted response problem related to scientific information about the drought. Differing pronouncements about the seriousness of the drought and its causes, including the potential that the drought was due to the Greenhouse Effect, led to confusion in decisionmaking. A fifth response problem noted was that even when information about the severity of the drought was available, many agencies and industries reacted extremely slowly. This apparently relates to a lack of experience and no available contingency plans. Considering the extent of public anxiety in drought areas, and the high loss of life due to the heat wave, there was an amazingly little government attention to the effects on humans. The lack of a standing or permanent interagency drought task force was obvious in reacting to the developing 1988 drought or the continuing drought into 1989.

Given these response problems and the findings as to sizable impacts, what were some of the lessons learned from the drought, at least those that would help minimize future losses to drought? Several of these lessons relate to the federal government. Clearly, all federal agencies impacted by the drought (water and agriculture particularly), need contingency plans. Even for those with plans, particularly at the basin scale, need to be updated.

Models defining relationships between climate conditions and various functions or activities (crop yields, forest management, forest growth, etc.) need to be developed or if they exist, they need to be updated to deal with changing cultural conditions. The nation needs to establish a standing drought task force at the high levels.

Improvements in drought monitoring and prediction are needed. Organizations with clear lines of responsibility need to monitor impending drought and to assess its status on regional and local scales. Research will be needed to improve drought-related predictions.

A federal program is needed to deal effectively with the issue of protecting human life from heat-caused deaths. This involves education, provision of equipment, and a variety of other activities to aid the low income elderly from unnecessary death.

Changes in federal policies are needed. These include the need to make new policy about how damaged agriculture is to be served, whether by crop insurance or by special relief funds. Agricultural policies relating to size of grain reserves and export policies must be redefined, as should policies relating to forest protection and fire management. In general, the ever growing population, coupled with diminishing resources means that the nation must have greater flexibility in its systems.

SUMMARY

Overall, national analysts saw the effects of the drought of 1988 as relatively minor in terms of the national economy. The Interagency Drought Committee's final report to the President concluded that there will be "little effect on the overall growth rate of the U.S. economy from the drought of 1988." When examined as GNP and Consumer Price Index effects, the national impacts do not seem significant. Nevertheless, the economic, environmental, and health impacts collectively make the drought of 1988 one of the nation's great natural disasters, and clearly it affected some regions and localities severely. It can be argued that several ameliorating factors, like surplus grain stores and federal monies earmarked for agricultural subsidies which could be changed to drought relief without impacting the budget, may not be as available during the next drought.

Although the environmental damages of the drought of 1988 are less well known than others, they may well be the most sizable and long lasting effects of the drought. Economically, the agricultural sector was hardest hit: the nation lost 31% of its usual grain production, which could have precipitated a food supply crisis had there not been large surpluses from prior years. Human health impacts included an estimated 5,000 or more deaths.

The total economic losses and costs of the drought were roughly $39 billion, though we suspect that this is an underestimate, and that later accounting of enduring and cumulative effects will increase the loss figure.

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AGRICULTURAL IMPACTS AND ADJUSTMENTS TO THE DROUGHT OF 1988-1989

by
Stanley A. Changnon, Jr.[1]

INTRODUCTION

The severe spring and summer 1988 dryness in the central United States, associated with a late summer heat wave, brought national attention to the "drought of 1988." In other areas such as California and the Pacific northwest, 1988 was the second year of drought, and in the southeastern United States, 1988 was the fifth year in an on-again-off-again drought situation that began in 1981. The Palmer Drought Severity Index at the end of July 1988 is shown in figure la. Notable in the pattern of drought is that portions of the United States, including the deep south and the southwest, were not experiencing drought in 1988, nor had they in the prior several years.

This report describes the known impacts and resulting adjustments to the continuing drought of 1988-89 (October 1988-June 1989). These impacts and adjustments can be thought of as two types: 1) those resulting from the drought conditions of 1988 in areas where the drought ended during the winter-spring of 1988-89, and 2) those effects and adjustments in areas which had either continued drought conditions into 1989 or had become drought-like during the winter, spring, and summer of 1989. The report begins with a description of the climatic aspects of the 1988-89 drought, and then impacts and adjustments to the 1988-1989 drought are presented according to major affected sectors: agriculture, transportation, water supplies, human health, and the environment. An updated assessment of the major losses from the 1988 drought conditions is also presented.

This report has been prepared to further illustrate the types and magnitude of climatic impacts in the United States, and to analyze the resulting adjustments including policy actions and their implications for future U.S. policy. The report also focuses on the nation's effort to monitor the 1989 drought and to interpret its impacts, done as a basis for identifying actions needed to improve the monitoring and interpreting of drought conditions. This report has been prepared as the 1989 drought continues into the fall of 1989, and results are presented with the two cautions: first, at this mid-drought time, certain impacts are likely unknown or ill defined, and second, relatively early and often unverified

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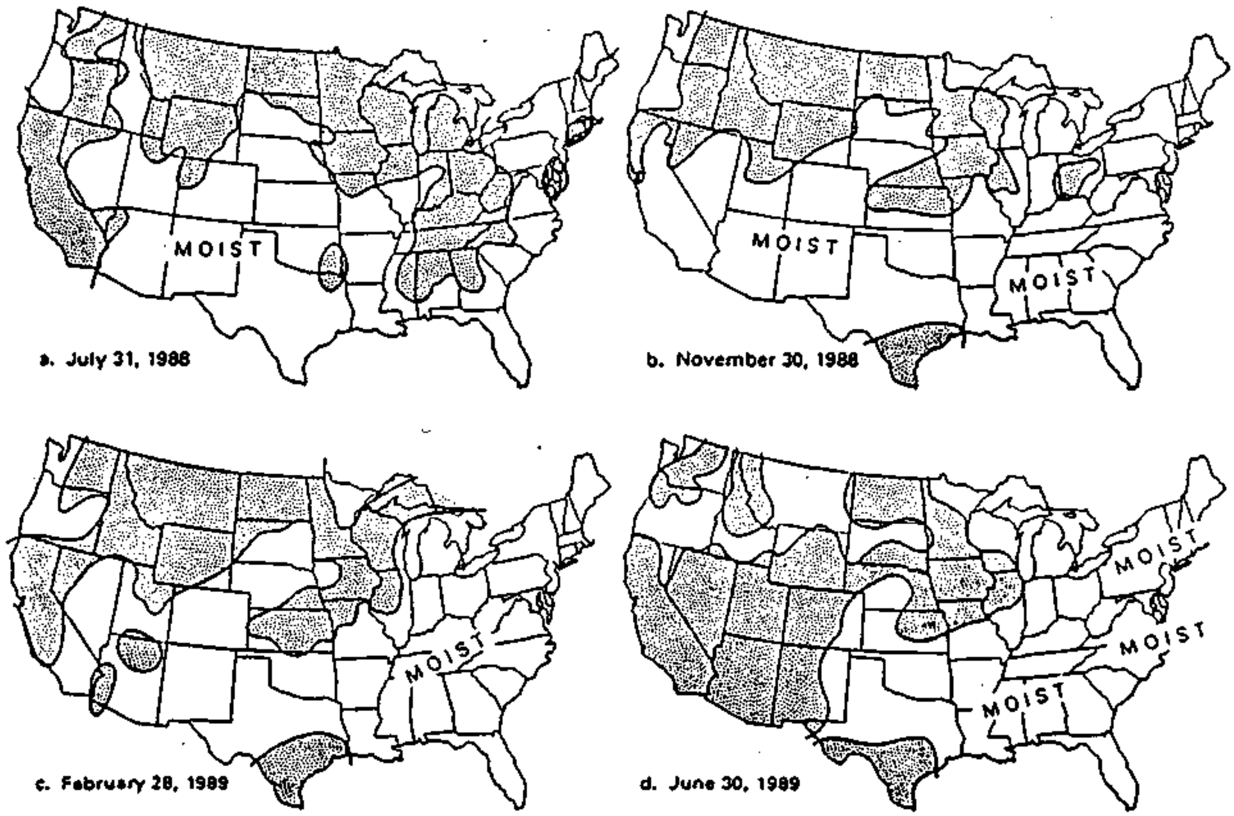


Figure 1. Areas of severe and extreme drought from mid-1988 to mid-1989 (Climate Analysis Center).

information about the reported impacts used may suffer from incorrect estimates of their true magnitude.

This study has been made with climate data and information from three sources: the five Regional Climate Centers (in the Northeast, Southeast, Midwest, High Plains, and Far West), the Climate Analysis Center of NOAA, and the National Climatic Data Center of NOAA. Considerable data on drought impacts have come from other sources including the government reports and the news media. As Changnon and Easterling (1989) have shown, highly useful information on drought impacts can be gleaned from news reports.

CLIMATOLOGICAL CONDITIONS

After the summer 1988 crops had been harvested, national interest and attention to the drought dwindled rapidly during the fall of 1988. President Reagan's Task Force on Drought summarized the drought effects and published their Final Report in December 1988 (Interagency Drought Policy Committee, 1988). No top-level federal attention was given to maintaining a drought monitoring or planning activity during the winter of 1988-89. The apparent belief was the problem had or would disappear, and if it returned, crisis management would be employed again, as in 1988.

Near to above average precipitation fell over many of the central and southeastern drought areas during the fall of 1988, further lessening fears over continued drought. Issuance of drought advisories by NOAA had ended. The drought severity pattern at the end of November 1988 is shown in figure lb. One notes that more intense dryness had developed in the central High Plains, and there was a continuing deficiency of moisture in the upper Rockies with apparent lessening of drought in California.

The only agricultural concerns were regional and were largely related to winter wheat being planted in the fall in the High Plains and Northwest. At the national level, worries about an "agricultural drought" in 1989 were not apparent. Concerns over "hydrologic drought," or deficient water supplies, did persist in portions of the western Midwest, the Missouri River Basin, and California. However, the winter is a period of low water demand and negligible evaporation; hence concerns over a water supply drought also did not surface at the national level at the end of 1988.

The winter (December-February) of 1988-89 brought, as usual, mixed amounts of precipitation across the nation. Many areas in the central U.S. and northeast experienced below normal snowfalls, and, in general, below normal precipitation prevailed in the High Plains and western Corn Belt. Figure 1c presents the drought pattern at the end of

February. At this time, the start of spring, four areas of serious drought were evident: 1) central California (again), 2) the central High Plains (Kansas), 3) the northern Rockies, and 4) the western Midwest. Dryness was beginning in the New York area. Fears were growing over the developing soil moisture shortage, particularly in the winter red wheat growing areas of Kansas, Nebraska, western Oklahoma, and west Texas.

Spring (March-May) conditions in the United States featured extremely heavy and persistent precipitation from eastern Texas eastward and northward up the Ohio River Valley and into New York and New England. The wet late spring with much above normal May rainfalls in the northeast, effectively ended the feared "hydrologic drought" in the northeast (Northeast Regional Climate Center, July 1989). It also terminated the drought-like conditions in the southeastern United States which had persisted since 1982 (Southeast Climate Center, June 1989). The spring precipitation, however, did not alleviate the agricultural drought (soil moisture) problems of the western Corn Belt and the central-southern High Plains (Midwestern Climate Center, June 1989). Winter and spring precipitation was also deficient in central and southern California, leaving the area in a drought position as shown in figure 1d (Western Regional Climate Center, May 1989). May rainfall in the western Midwest and southwestern U.S. ranked as the 16th driest in the past 95 years (Heim, 1989).

Drought conditions at the end of May 1989 were significant across the United States and more extensive than those in May 1988. For example, the areal extent of areas with severe or extreme drought in the U.S. was 31.5%, ranking as the 8th greatest areal extent since 1895 (see Table 1). In May, 43.8% of the Mississippi River Basin had extreme long-term drought, with only the May values of 1931, 1934, 1941, and 1954 exhibiting greater extents of severe drought (Fig. 2). For the Corn and Soybean Belt, the areal extent of extreme severe drought in May 1989 was 41.8%, ranking as the 8th largest value and greater than 1988. The drought severity pattern at the beginning of the 1989 summer is shown in figure 1d.

The south and east received very heavy late spring and June rainfalls. The areas of severe drought in the United States had shifted to the west (California, New Mexico, Colorado, Utah, Wyoming, and Nevada). On a national basis, the drought conditions that began early in 1987 were still persisting well into the summer of 1989 (see Fig. 1d). The spring of 1989 became the fifth consecutive spring season in the U.S. with below average precipitation. The only comparable historical period of consecutive dry springs was 1913-1917.

The information on figures 2, 3, and 4 demonstrate two important factors about the drought continuing into 1989. One is that severe drought conditions existed across large

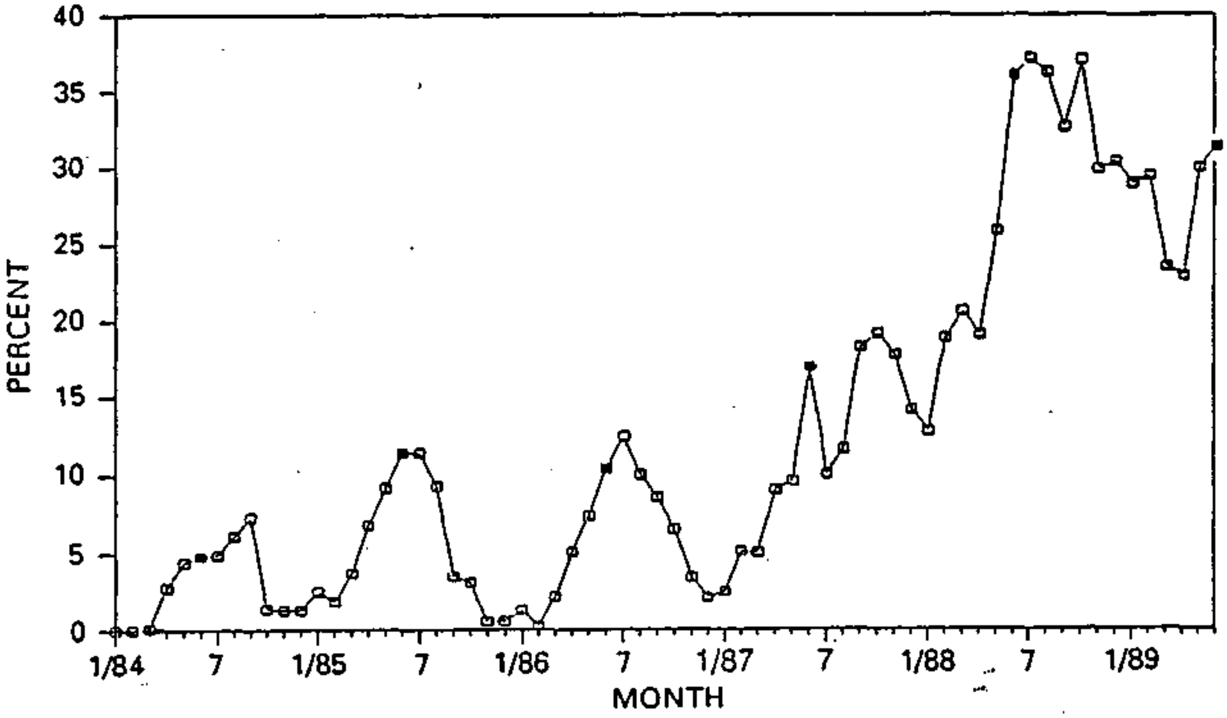


Figure 2. The areal extent of severe and extreme drought over the contiguous United States for 1984-1989 (National Climatic Data Center).

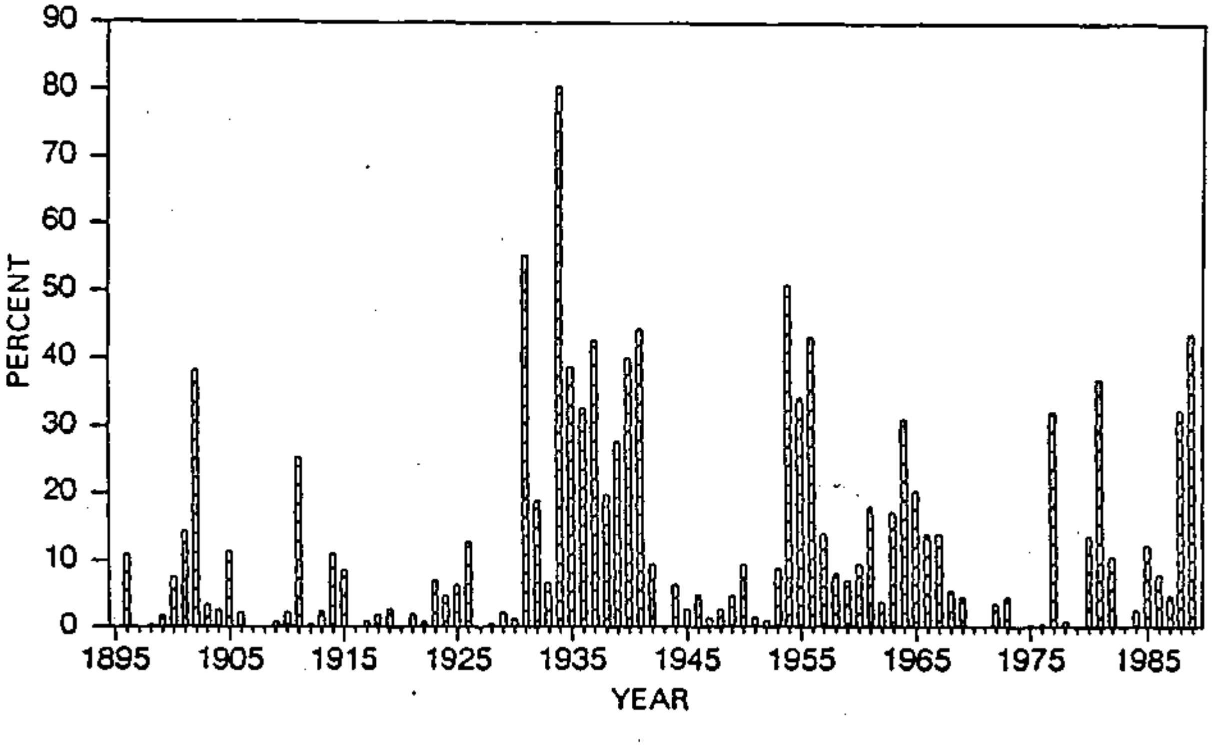


Figure 3. The areal extent of extreme drought in the Mississippi River Basin during May, 1895-1989 (National Climatic Data Center).

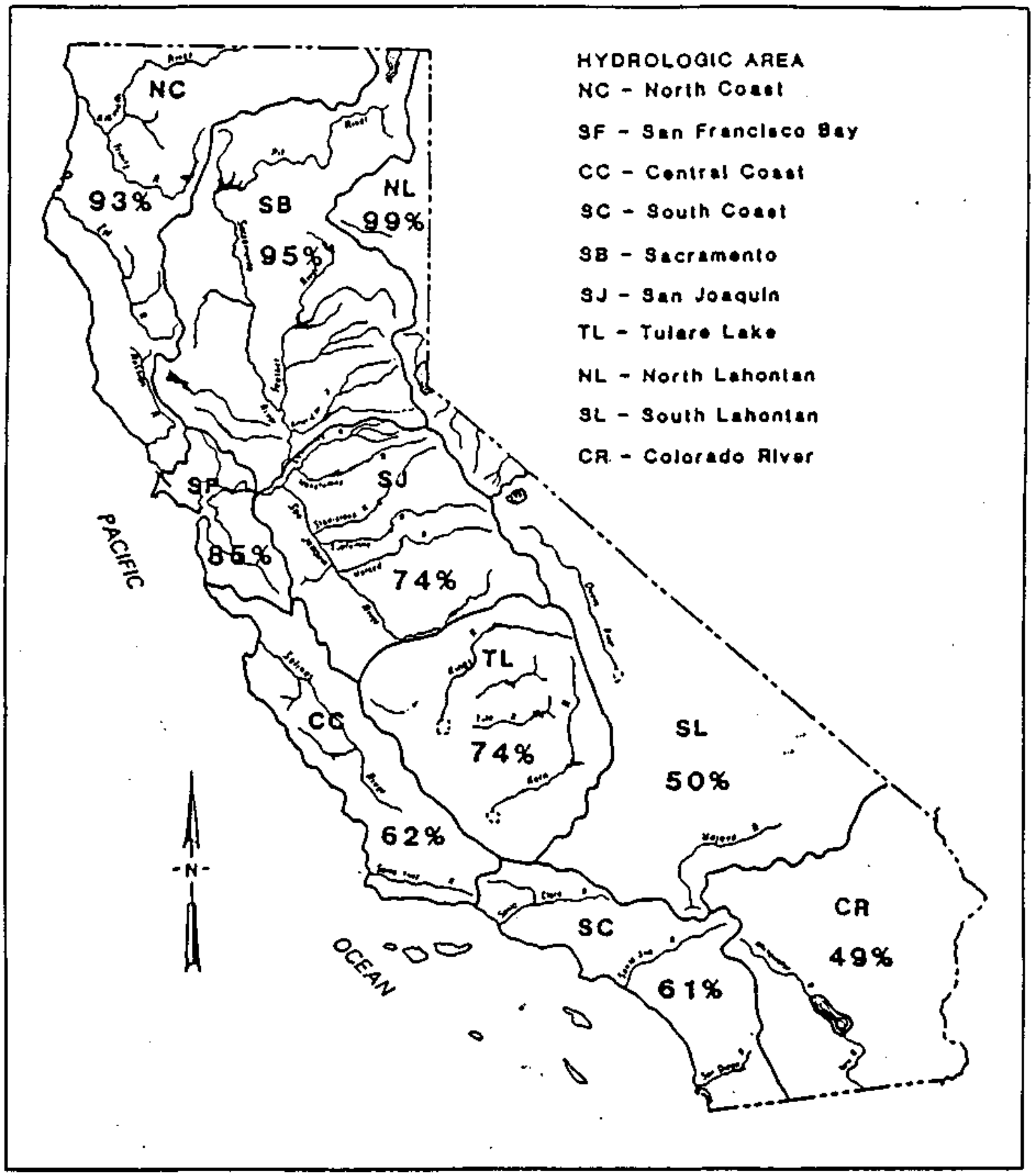


Figure 4. The percent of average precipitation in California basins for October 1988 through April 1989 (Western Regional Climate Center, 1989).

portions of the United States at the start of summer 1989. Second, the graph of drought extent for the period 1984 to June 1989 (Fig. 2) indicates that on a national basis, the drought that began in early 1987 had persisted through the first half of 1989. This was contrary to the early spring predictions of the U.S. Department of Agriculture which indicated little chance for drought continuing into 1989. The primary locations of drought in 1988 had largely shifted to different parts of the nation by June 1989 (CAC, July 1989). The graphs by Heim (1989) for Nebraska and Kansas (Figs. 5 and 6) show that the winter 1988-spring 1989 precipitation values, the period of winter wheat growth, were extremely low (lowest on record for Nebraska and third worst in Kansas).

Table 1. Mays having as much or more of the contiguous United States in severe or extreme long-term drought than May 1989.

Year	Percent of U.S.
1934	57.0
1931	37.1
1956	35.8
1955	35.3
1954	34.4
1977	33.1
1902	32.5
1989	31.5

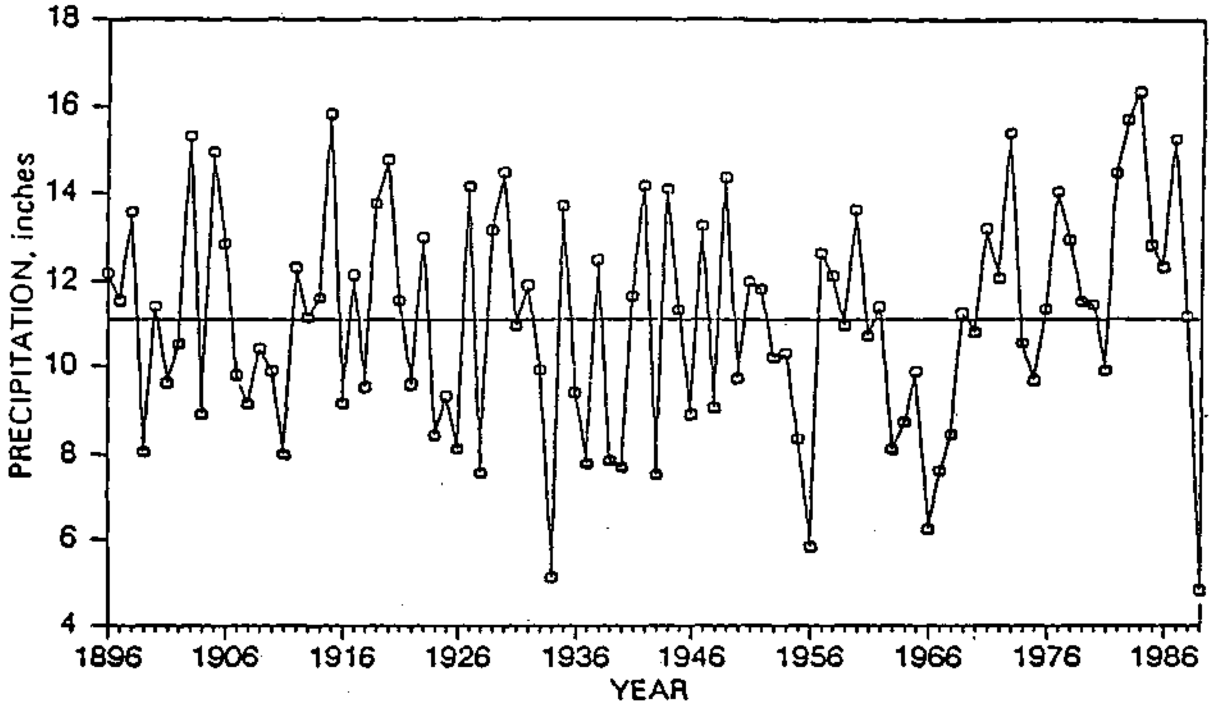


Figure 5. The October-May precipitation for 1895-1989 in Nebraska (National Climatic Data Center).

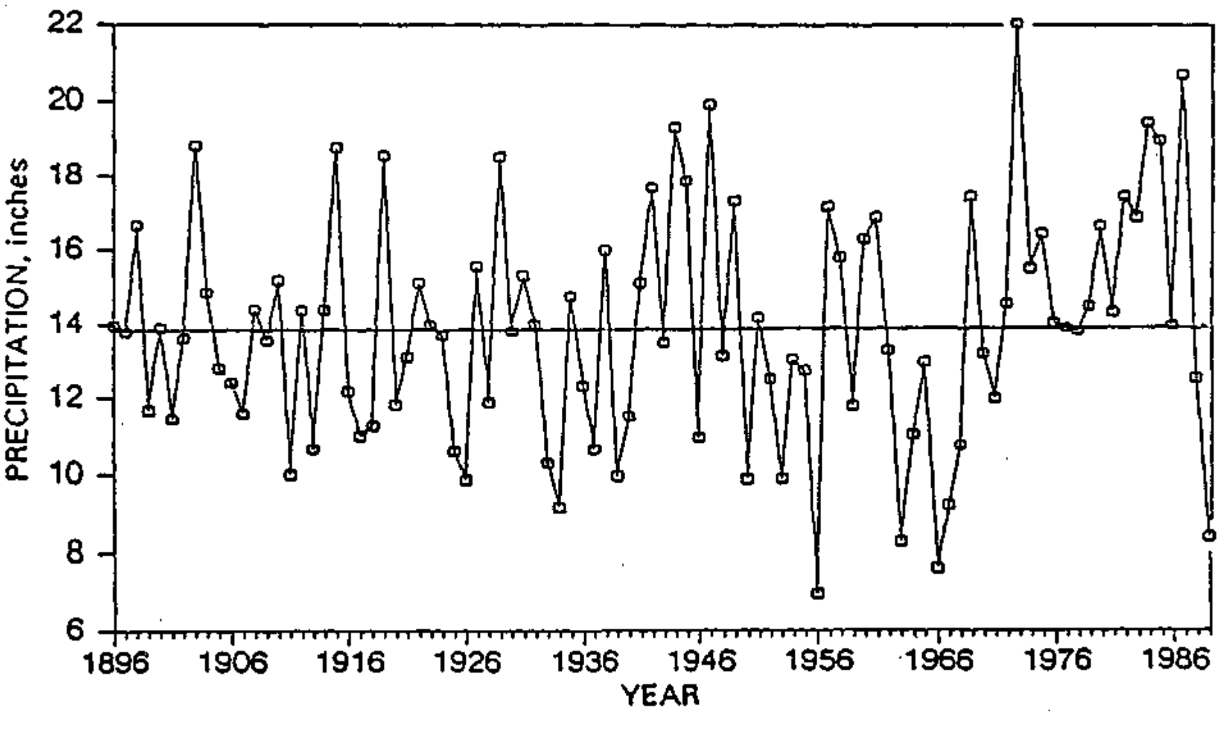


Figure 6. The October-May precipitation for 1895-1989 in Kansas (National Climatic Data Center).

AGRICULTURAL IMPACTS

The continuance of the drought into the first nine months of 1989 had its greatest effects on U.S. agriculture. These effects reflected a continuing financial instability for many individual fanners, agribusiness, and the farm markets. The agricultural effects also led to considerable governmental attention to drought with many adjustments offered, and a few accomplished, between January 1 and August 31, 1989. Clearly, the agricultural drought effects and adjustments were of great regional and national concern (USA Today, July 27 and August 30, 1989). The agricultural effects of the 1988-89 drought are presented according to those 1) at the individual level, the winter wheat farmers, the livestock producers, the midwestern corn and grain farmers; 2) the grain market; 3) agribusiness; and 4) leading to the governmental adjustments to these impacts.

Winter Wheat Farmers

One of the three most notable areas of individual impact of the 1989 drought, was to the winter wheat farmers in Kansas, Nebraska, Oklahoma, and west Texas. Kansas and Nebraska in particular experienced the greatest weather problems. Problems began as the drought intensified during a dry fall of 1988; then this was followed by an overly warm December and January, which was ended abruptly by an extremely cold February (a combination leading to "winter kill" to the young winter wheat plants); then late winter-early spring dust storms damaged the young wheat; and finally much above normal temperatures (days in the 90°F level) came in April and May along with low precipitation to further damage the wheat crop (see Figures 5 and 6).

Winter wheat comes in three types and each is grown in a different area of the United States. Hard red winter wheat (the type used for bread) is grown in the southern and central High Plains (Nebraska, Kansas, Texas, Oklahoma); soft winter wheat is grown largely in the Corn Belt and is used for products like crackers; and white winter wheat is grown in the northwest and is used largely for export to the Orient. Thus, damages to the hard red winter wheat crop of the High Plains could lead to problems in wheat supplies for bread, and in turn, to increased consumer prices. The USDA reported in January that the planting of winter wheat, which had been done in the fall of 1988, was down 12% from that in prior years (Champaign News-Gazette, January 17). This reflected soil moisture concerns of the Great Plains farmers based on the dry conditions during the fall-winter of 1988 (see Fig. 1b).

Problems with the hard red winter wheat crop became national news by early April. At that point it was announced that at least 25% of the Kansas wheat crop had been lost due to the drought with similar problems in west Texas, Oklahoma, eastern Colorado, and Nebraska (Los Angeles Times, April 10). The damages at that time led economists to speculate that bread prices would rise 10% during 1989.

The drying effects of the drought in the winter wheat sectors of the High Plains led to dust storms in April. The dust clouds spread eastward to Illinois and Indiana (Los Angeles Times, April 10). The blowing dust particles damaged stems of the winter wheat plants.

Political attention to the problems in the High Plains became evident in early April. Congress and the USDA began to debate the severity of the problem and the potential adjustments (see section on Government Reactions and Adjustments). Questions were being raised as to whether it was "too late for rain to help?".

By mid-April, the Kansas Wheat Board reported that 76% of the winter wheat was in poor condition. By late April, the estimate was that 48% of the winter wheat crop had been lost in Kansas, and the Kansas members of Congress were after the Bush Administration to act (Chicago Tribune, April 23). It was further reported that 30% of the winter wheat acres would be abandoned; that is, not worthy of harvesting.

The USDA, continuing its cautious approach to addressing the problem, announced on April 27 that the "total" wheat harvest of the United States would be up considerably from 1988 when the U.S. production had dropped to 1.81 billion bushels (due to the 1988 drought). The USDA expected the 1989 wheat crop to produce 2.1 billion bushels, but notably it would not be enough to rebuild depleted U.S. stockpiles (AP, April 27). The USDA forecast for wheat stocks as of June 1, 1989, was for a meager 549 million bushels, down 1.3 billion bushels from June 1, 1988 and down 1.82 billion bushels from June 1, 1987.

Amidst growing concern in Kansas over the winter wheat crop, federal responses to the requested federal relief actions were not forthcoming. The USDA, on May 11, announced that Kansas, Nebraska, Oklahoma, and Texas wheat production would be down 30%, with the U.S. winter wheat total production down 8% from 1988 (Chicago Tribune, May 11). However, Kansas winter wheat production was predicted to be down 37%, with the national total hard red wheat production for 1989 down 21% over the prior-year average. The winter wheat loss estimated at $800 million (McGraw News, May 11). The wheat reduction predicted by USDA of only 8% nationally was due to the expected high yields of soft red winter wheat in the Midwest which was predicted to be above average (Chicago Tribune, May 12). The USDA admitted in May that U.S. wheat exports would decline by 300 million bushels from prior years for the year beginning June 1, 1989. In general, the federal government in the late spring was portraying the U.S. wheat picture in an optimistic manner, and in effect down playing the regional problems of the red winter wheat farmers in Kansas, Oklahoma, and Texas (Reuters, May 12).

Extremely high temperatures in the High Plains during late April and early May with maximum temperatures in the 90's on several days brought further damage to the wheat crop. Yet, the USDA pronounced on May 15 that "U.S. wheat production will meet world desires and the losses of the High Plains would not essentially affect our production" (U.S. News and World Report, May 15). Winter wheat harvest began in Texas and Oklahoma in late May with the wheat crop still predicted to be bad in Kansas. The yields in Kansas were reduced 38%.

Kansas and other winter wheat area farmers with losses waited with concern as Congress debated when and how much aid to extend to them during June, July, and August. By mid-July, USDA had shifted its views from "relief only for the winter wheat farmers" position to expanding drought relief to many other crops (AP, July 12). The 1989 wheat damage in Kansas was estimated in mid-July as creating a statewide production of 211 million bushels, as compared to 323 million bushels in .1988, a 35% reduction (Farm Week, July 17).

Problems with the 1989 spring wheat crop in the northern plains became an issue. In mid-July, the Governor of North Dakota estimated the statewide crop losses at $540 million due to the spring wheat (Reuters, July 17). In its August 1 crop report, the USDA estimated that the U.S. spring wheat crop production would be 12% less than the USDA July 1 estimate. The extent of the losses to the spring wheat crop were still being estimated when this report was prepared, but yields were depressed in Montana, North Dakota, and South Dakota (USA Today, August 30). Regardless, the 1989 wheat production was severely impacted by the 1989 drought. In late August, the USDA announced that the "lingering drought" continued to drain U.S. grain reserves (New Gazette, August 25b). World stockpiles of wheat are the lowest since 1975. By the end of August, the USDA estimated the annual production downward to 2.04 billion bushels which was 13% above 1988 (News Gazette, August 25b). This compares to annual usage, including exports, of 2.29 billion bushels. The USDA predicted exports would decline 10%, to less than 1.3 billion bushels. The drought of 1989 had produced sizable impacts. The new estimate for the June 1, 1990 stockpile of wheat was for 474 million bushels, down 15% from the 1989 stocks.

Livestock Producers

The second group of individuals severely affected by drought during the winter-spring 1989 were livestock producers with herds in the states of Iowa, Missouri, Nebraska, Kansas, Oklahoma, Texas and New Mexico. The winter and spring (March-May) precipitation values in these states were low. The 1989 spring ranked as the second driest since 1895 in Nebraska and New Mexico, fifth driest in Colorado, 9th driest in Iowa, 11th driest in Kansas, 15th driest in Missouri, and 18th driest in Oklahoma and Texas (Heim, 1989).

The drought problem producers experienced was two-fold. First, continuing drought in these feeding areas had greatly reduced the quality of grass in their pasturelands. Second, the 1988 drought in the Corn Belt led to low production of corn and soybean meal which had greatly increased the prices of these feeding supplements for livestock (News-Gazette, May 11). Thus, the impact of the drought of 1988 on livestock producers became extremely serious during the spring of 1989 (High Plains Climate Center, May 1989). Assessments in May 1989 revealed, for example, that U.S. food prices in 1989 were going to rise 5.5 to 6% due to the drought, and principally due to the cost of feeding livestock. This increase of up to 6% (acknowledged by the USDA in May 1989) was much higher than the USDA had forecast in November 1988 when it predicted a 1989 rise of 3 to 5%. Secretary Yuetter of USDA announced on June 30 the increase in food prices in 1989 would probably be 7%, reflecting an ever growing increase in food prices related to drought (and a serious estimation error on the part of the USDA). It was further announced in May 1989 that the effect of the drought of 1988-89 would produce a major and long-term impact on the U.S. beef industry due to the poor pastures and increased feed prices (News-Gazette, May 11).

The continuing problem of the U.S. livestock producers was evident in Congress beginning in early April, and a series of "relief actions" were accomplished by the federal government (see section on Government Reactions and Adjustments).

Examples of the problems faced include the price of hay in the Midwest (UPI, April 24). In April 1988 hay cost $65 a ton in the Midwest, but it had risen to $131 a ton by April 1989. In Iowa, 78% of all pastures were defined as "dry" by mid-April. The Governor of Iowa announced on April 25 that 40% of Iowa's pastures were ruined for cattle in 1989, and further reported that liquidation of cattle herds in Iowa had begun because of the lack of pastures or producers inability to afford feed at the higher prices (UPI, April 25).

Further problems were noted in May when an abnormally large number of hog deaths were reported. These were attributed to the poor quality of the 1988 grain and its high toxin content (AP, May 11). The problems of cattle raisers in the High Plains continued to be severe into May and June. It was reported during May that cattle slaughters in Missouri and

Kansas were up 50% over those in 1988 (Financial Times, May 19). The federal government performed a series of actions aimed at relieving the stress on the livestock producer.

The continued drought into the summer of 1989, with higher grain prices both from the 1988 and 1989 drought seasons was predicted to lead to a major liquidation of the national hog herd (Farm Week, July 3). This was expected to lead to a cut in pork production in 1990. The drought had not only produced higher feed costs, but had weakened hog prices and brought low returns to the producers. By June 1, 1989, there were 3% fewer breeding hogs than on June 1, 1988, as hog producers adjusted to the drought problems. As the summer of 1989 progressed, USDA continued to expand its assistance to livestock producers through allowances for haying and grazing. By late July, it was noted that the number of cattle in feedlots was down 6% in the 13 major states of production over the July value in 1988 (Farm Week, July 24d). By late summer, the USDA announced that the increased grain production of 1989 (over that in 1988) would lead to lower feed prices and in turn this would lead to increased poultry production (News Gazette, August 18).

Corn Belt Farmers

The principal impacts to farmers not involved in winter wheat or 1989 livestock problems occurred in the Midwest. There, farmers had suffered extreme drought in 1988 but were not experiencing crop problems with another drought until the summer of 1989. Certain effects were "delayed" from the 1988 drought and were occurring during the winter and spring of 1989. The Midwestern drought was voted the top news story of 1988 on January 1 (News-Gazette, January 1).

It was announced (in early March) that most Corn Belt farmers would participate in the grain set-aside (feed grain program), with only an expected 10% of all lands set-aside to fallow. However, many farmers could not afford additional land planting costs in 1989 as a result of financial losses from the 1988 drought (News-Gazette, March 5a). It was further announced in early March that the 1988 drought had hurt the performance of pre-emergence herbicides, and that Corn Belt farmers would have to use a greater amount of pre-planting plant herbicides to control weeds (News-Gazette, March 5c). The drought of 1988 was being assessed in the Midwest during the spring of 1989 as one in a series of bad years economically for Corn Belt farmers that had begun in 1980 (News-Gazette, March 4).

The early March assessment of drought effects in the Corn Belt was typified by the situation facing Illinois farmers. Crop yields in 1988 had been reduced by 30 to 40%, but the positive effects were that corn and soybean prices had increased during part of 1988, as shown in figure 7 (News-Gazette, March 5d). Another negative effect was that livestock and hog production costs had risen as a result of increases in prices of soybean meal. Since the amount of set-aside land had been cut back for 1989, this action which would cause grain prices to go down. Further, farmers had considerable concern over the effect of aflatoxin, a toxic mold found in 1988 corn due to the drought and present in the 1988 corn stored for 1989 feeding.

Increases in farmland prices in the High Plains and Midwest occurred, largely as a result of "benefits" to many farmers resulting from the 1988 drought (News-Gazette, March 5e). These benefits accrued only to those who had irrigated their crops or to those who had carryover stocks from 1987 and sold them off at the higher prices generated by the 1988 drought. The USDA announced farm land prices were up 67% due to the drought (Chicago Tribune, May 8).

Planting of corn and soybeans in Illinois, Iowa, and Missouri by May 1, 1989, was behind average. Chief Meteorologist Strommen of the USDA announced (Reuters, April 26) on April 26 that he was "optimistic" about crop prospects for all U.S. crops planted in the spring because drought-related weather patterns were not prevalent. However, soil moisture on May 1 was reported low over 48% of Illinois, 50% of Missouri, and 68% of Iowa (News-Gazette, May 2), and the NOAA-issued drought analysis indicated serious soil moisture problems in the western Corn Belt and High Plains (CAC, May 1989). The general USDA expectation was that acreage planted to corn in 1989 would be increased due to government incentives. However, excessive spring wetness in Indiana and Ohio reduced corn planting by about 2 million acres less than the 73 million acres expected (Farm Weekly, June 26). Illinois corn-soybean farmers facing their second year of drought at the end of August, decried the optimistic spring weather forecasts by meteorologists (Farm Week, August 21a).

On May 7, a USDA announcement indicated that the 1988 drought had put between 10,000 and 15,000 of the nation's 550,000 commercial farmers out of business (Los Angeles Times, May 7). The announcement indicated that a second dry year in 1989 would force an even larger number of farmers out of business. Another financial impact of the 1988 drought in the Midwest was related to farm loans. The demand for farm loans during the spring of 1989 was up 15% from that of 1988 (UPI, May 16d).

Another impact of the 1988 drought was being realized in potato farming. It was announced in May that the 1988 drought had caused a major loss of potatoes including seedlings in Wisconsin and Michigan, and prices were up from $6 a barrel in 1988 to $20 a barrel by May 1989 (UPI, May 13). Potato growers in Maine were benefitting from the Midwestern losses, but by late May their stock of potatoes was nearly depleted. Similarly, the cherry crop in Washington and other states was expected to be increased in 1989 (over

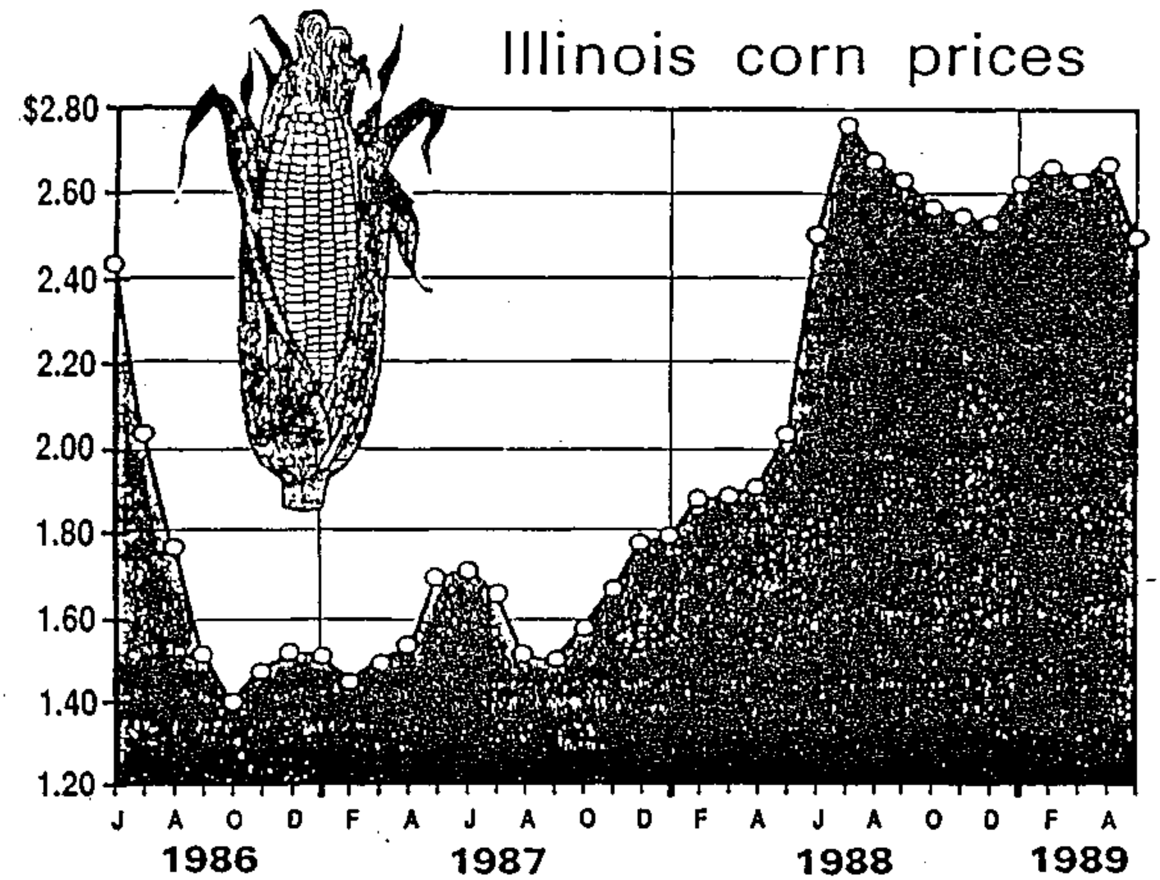


Figure 7. Monthly fluctuations in prices of Illinois corn, 1986 to 1989 (Farm Week).

1988), but to be less than average (AP, June 29).

By the end of May 1989, a considerable climate contrast existed in the Midwest for the corn and soybean farmers (Midwestern Climate Center, June 1989). In the eastern Corn Belt (Indiana and Ohio) the spring weather had been unusually wet and cold, leading to delayed planting (Christian Science Monitor, May 17). Furthermore, delayed planting had increased the farm requests for short duration corn hybrids and hybrid supplies of this type were not adequate to meet the demand (UPI, June 16). Many shifted to soybeans, and Ohio expected its 1989 yields of corn and soybeans to be 30% below average (UPI, June 5b). On the west end of the Corn Belt (northwestern Illinois, large parts of Iowa, northern Missouri, and southern Minnesota), the opposite condition existed (Farm Week, June 5, June 19). There, soil moisture was inadequate, as of June 30, to result in average corn yields. Rains in July would be critical (Farm Week, July 26a).

In early July a new problem related to the drought of 1988 became apparent in the Corn Belt. Herbicides applied to soybeans in 1988 were left in the soil due to deficient 1988-89 precipitation, and in such fields where corn was planted in 1989, damages began to appear by the end of June (Farm Week, July 3c). This problem escalated in Iowa with a group of farmers filing a class action suit against three firms producing the herbicides (American Cynamid, Elanco Products Company, and MFC Corporation). The farmers claimed that the products had hurt corn in Iowa, Illinois, Nebraska, Wisconsin, Michigan, Indiana, and Ohio from 1988 applications. The chemical firms reacted and collectively developed a pact (Farm Week, July 24b). The companies agreed to handle farmers damage claims, but only after company officials perform in-field assessments. Losses would be paid by the three chemical companies involved.

The first two weeks of July were notable in the Corn Belt and the High Plains for having much above normal temperatures and very little precipitation (Chicago Tribune, July 8). Concerns grew rapidly during this sensitive period of corn tasseling and pollination when hot, dry conditions can be very damaging to corn. The USDA's July 1 estimates relating to corn production and surpluses showed major decreases over earlier estimates. The 1988 fall surplus was 4.25 billion bushels of corn and 302 billion bushels of soybeans; but by July 1 their estimates of 1989 (fall) surpluses were down to 2.0 billion bushels of corn, and 125 billion bushels of beans (Farm Week, July 10a).

Concerns continued during July over the weather stress to Corn Belt crops (CAC, July 1989). Rains were very isolated and it was difficult to estimate effects on yields (Farm Week, July 10b). The weather stress of July in the Corn Belt and High Plains became national news with awareness that damage to the corn crop was occurring for the "second year in a row" (Reuters, July 12).

Drought-related problems of other types prevailed. For example, 1989 grasshopper outbreaks in Minnesota had led to an estimated $20 million loss and special insecticide legislation was passed by the Minnesota legislature, leading to clashes with environmentalists (Los Angeles Times, July 16). Drought damages to the spring wheat crop led the Governor of North Dakota to declare the state a disaster area. In the midst of growing worries, the USDA issued new estimates about acreage planted (Farm Week, July 17b). The 1989 acreage in soybeans planted was 61.3 million acres, 4% more than 1988 and 6% more than 1987. The corn acreage planted was estimated at 72.7 million acres, also higher than the 67.6 million acres in 1988, but less than the USDA's March 1 estimate of 73.3 million acres of corn. The North Dakota spring wheat losses were estimated on July 17 at $540 million (Reuters, July 17).

The Corn Belt weather changed dramatically during the week of July 16-22 with widespread rains of 1 to 3 inches (Midwestern Climate Center, August 1989). These rains were noted to have fended off crop disaster (Farm Week, July 24a). Corn crops in western and northern Illinois, large parts of Iowa, and parts of Missouri and Minnesota were not "made" but were saved from likely disaster. At this stage, the USDA announced for the first time that it would support relief aid to U.S. corn growers due to the drought of 1989 (News Gazette, July 25a).

Concerns then began to focus on soybeans in the Corn Belt which depend heavily on August rainfall conditions to produce good yields. The outlook for conditions were seen as good in Illinois according to the agricultural experts (News Gazette, August 4). One benefit related the generally wetter and cooler conditions of the 1989 summer than those of 1988 was the reduction and concerns over the aflatoxin content in corn, a major problem in 1988. The lower temperatures in 1989 reduced the threat of a repeat of an aflatoxin outbreak (News Gazette, August 13).

Early August crop assessments performed by the private firms and USDA produced important new views. One major impact was that the August 1 USDA crop report showed their expectations for the 1989 corn crop had decreased to 7.35 billion bushels (and less than most private firm expectations) (Farm Week, August 14b). Scientists issued words of caution of another weather problem, the likelihood of early frost (Farm Week, August 28a). The expected U.S. surplus of corn in the fall of 1989 was reduced to 1.68 billion bushels from the 1.83 billion estimated one month earlier, July 1. Bean production was similarly downgraded in August with a reduction in expected yield per acre from 33 to 32.3 bushels. By late August, 47 percent of the nation's soybean crop covering 19 states was judged as fair to very poor, reflecting the drought effects (Farm Week, August 21a).

Late rains in August across the Corn Belt of 0.5 to 3 inches in most areas produced mixed effects. It promised to help yields of late maturing soybeans but it also delayed maturity of crops and increased the likelihood of "late harvest" and threat of frost damage (News Gazette, August 25a). The 1988 drought induced corn and soybean losses led to use of most supplies in elevators across the Corn Belt, and elevators faced the 1989 harvest with adequate space for storage. The drought of 1988 and 1989 (low soil moisture levels), coupled with below normal spring 1989 temperatures, led to late planting of corn and soybeans across much of the Corn Belt. Later crop maturity brought forth fears of major losses due to early frosts. Two private sector meteorologists issued late August forecasts indicating a high likelihood of earlier than normal frost in the Corn Belt (Farm Week, August 28a and b).

The final verdict for soybean yields and drought effects for 1989 are as yet unavailable. Figure 8 depicts the uncertainty that existed over bean yields in late August, as well as yield fluctuations in recent years. Farmers in Illinois and Iowa were seeking in late August, governmental relief (Farm Week, August 21b). Iowa corn yields were assessed downward in late August and were predicted to be less than the 110 bu/acre prediction for statewide average yields issued by USDA on August 1 (Farm Week, August 28b).

Agribusiness

Most U.S. agribusinesses had been affected by the 1988 drought, in both positive and/or negative ways. Many large agribusinesses during the summer of 1988 had developed corporate drought task forces, and these in turn evolved new plans for marketing, production, and sales in 1988-89. One company formed its own weather information group, and increased purchases of weather information and climate predictions were noted in 1988 and continuing into 1989.

One agribusiness sector considerably affected by the drought was the weather insurance industry. The Farm Relief Act of 1988 required that any farmer accepting relief payments would have to purchase all-weather peril insurance during 1989 and 1990. Thus, sales did increase in 1989, and purchases of crop-weather insurance were much above levels expected by major insurance companies, nearly doubling the 1988 sales level.

Several Midwestern seed growing firms experienced severe losses of seed crops in 1988 (News-Gazette, March 4). Thus, during the 1988-89 winter season, they took out contracts to grow large amounts of seed crops in Texas, Florida, and South America. Several firms also had largely consumed their hold-over stocks in attempting to meet 1989 demands for seed corn and soybean seed. There was insufficient short-term hybrids available for Indiana and Ohio farmers facing a short season due to late spring wet and cold conditions.

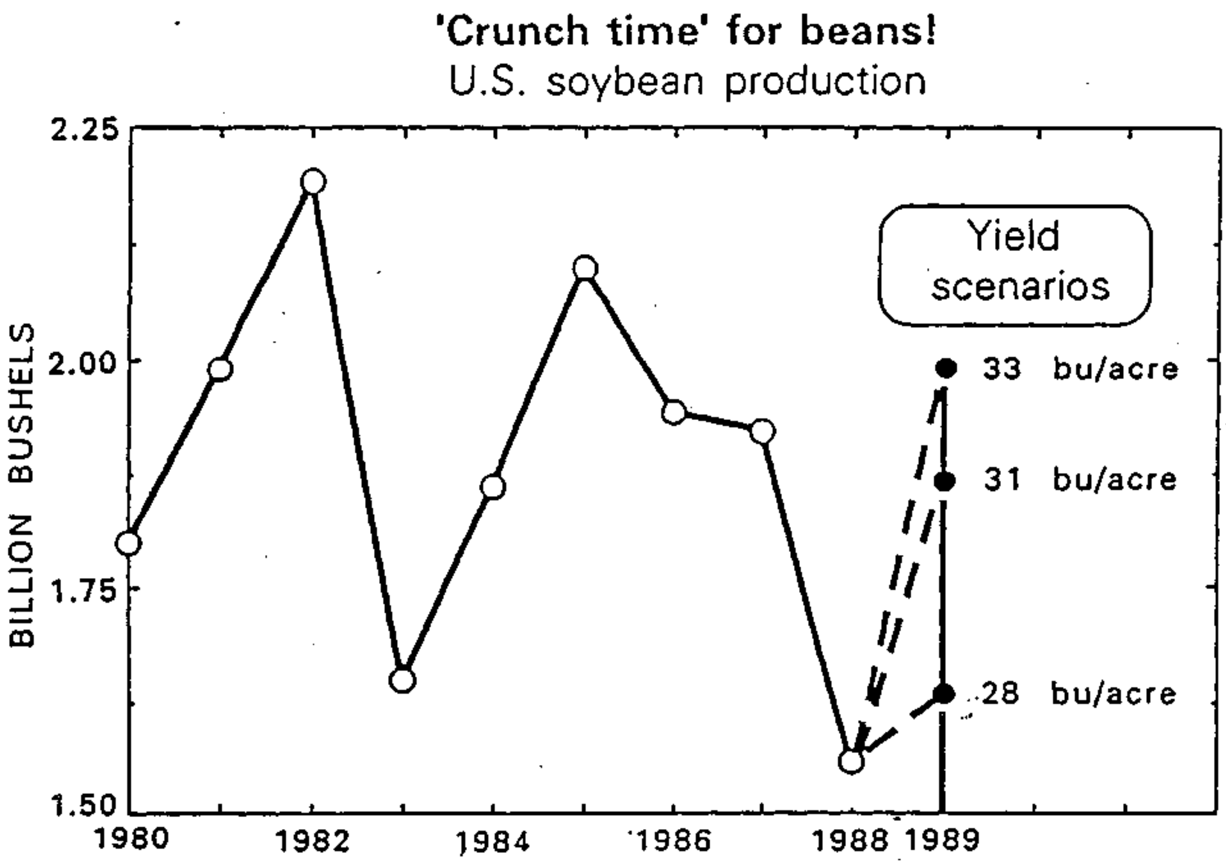


Figure 8. Fluctuations in U.S. soybean yields and late August Scenarios for 1989 yields (Farm Week).

The farm machinery manufacturing industry announced in March 1989 it was enthusiastic about future sales in 1989 (News-Gazette, March 5d). However, retailers of farm machinery were not optimistic about large sales in 1989. Optimism about purchases, both of farm machinery and farmland, developed because there were low carryover stocks, higher commodity prices were expected, an expected increase in farm income, and with more land going into production in 1989 due to government incentives to grow more grain.

Another agribusiness severely affected by the 1988 drought was the rain insurance industry. The CHUBB Insurance Group paid out (on April 20) $19.2 million in 2,838 checks to farmers in 10 states who had settled a lawsuit over rain insurance (News-Gazette, April 21). CHUBB had already paid out $37.4 million to farmers for their insured losses. Litigation had involved more than 7,257 farmers. In turn, the CHUBB Group and 8,800 farmers jointly sued Good Weather International Corporation (the company in the CHUBB Group that provided the 1988 rain insurance coverage) for an undetermined amount. They accused Good Weather of selling more policies than CHUBB had authorized (UPI, July 13). A trial began on July 12 in Cincinnati in the U.S. District Court with the farmers asking damages of $20 million in addition to unspecified punitive damages against Good Weather International Corporation. This activity was in addition to the agreement between the farmers and CHUBB for a settlement of $48.1 million made in November 1988 to meet farmer claims. CHUBB claimed that Good Weather violated its contract by selling too many crop insurance policies and claimed that Good Weather owed CHUBB at least $75 million because of the payoff costs and fees for the lawyers CHUBB had hired. In turn, Good Weather denied all claims by the farmers and CHUBB. By mid-August, the law suit had been settled out of court. The farmers endorsed a settlement of $4.93 million to them with $3.7 million to CHUBB Corporation (News Gazette, August 15) from Good Weather International Corporation, indicating willingness of the lawyers to settle because they considered Good Weather now had a "negative worth."

Agribusiness financial groups including farm banks also were affected. This involved the bankruptcy and abandonment of 10,000 farms with many mortgaged with local farm banks. However, most banks in the Midwest reported no major losses in 1988 (UPI, June 1). Also, farm loans had increased in the spring of 1989 by 15% over the number in 1988.

Firms owning grain elevators in the Corn Belt were heavily impacted by the 1988 drought. Large surpluses in storage from 1987 were systematically reduced during late 1988 and 1989, and the railroads and barge shippers continuously moved grain out of the Corn Belt in the spring and summer of 1989. Thus, the elevators had room to store the 1989 harvest of corn and soybeans (News Gazette, September 3). The grain storage companies expected to realize increased income in late 1989-1990 because farmers would be paying more to have the late maturing crop dried at the elevators, and because of increased storage income since farmers were expected to hold and not sell (News Gazette, August 25a).

Governmental Reactions and Adjustments to the 1989 Agricultural-Drought Problems

Most state and federal governmental reactions to the agricultural drought problems during the winter and spring 1989 were due to two areas of concern: the problems of the High Plains winter wheat farmers and the problems of the livestock producers concentrated in the western Corn Belt and the High Plains. During the summer of 1989 concerns over drought effects to the Corn Belt brought further governmental actions.

Governmental reactions to these three agricultural problems first appeared during the spring of 1989 when Senator Bond of Missouri announced in early April that Congress would need to provide drought relief in 1989 to address the wheat problems in Kansas (UPI, April 4). Prior to that, few changes in agricultural policies were foreseen in Congress (News-Gazette, March 5b).

The winter wheat problems became national news during the first week of April, and by April 9, members of Congress had begun drafting disaster relief legislation for wheat farmers (Reuters, April 10). At the same time, the Bush Administration and the USDA disagreed with Congress about the need for relief, indicating that the severity of the drought was still uncertain and that it was too early to react (Los Angeles Times, April 10). The USDA's chief meteorologist was quoted in March as saying it was too "premature" to assess the 1989 drought and that weather patterns of 1989 were different than that of the 1988 drought patterns (Los Angeles Times, April 10).

The major initial debate was whether it was "too late for rain to help the crop." Essentially USDA was saying "no, it's not too late," whereas the wheat farmers and their Congressional members were saying "yes, that it was too late." The winter kill of the wheat also had disastrous effects.

Arguments raised in early April in Congress concerned whether to use relief measures for the wheat farmers or to allow national crop insurance to serve those who had decided to purchase it (Reuters, April 10). Failure of crop-weather insurance to be widely purchased by the U.S. farming community had been a continuing problem since 1982. Disaster payments had been stopped in 1982 basically to encourage the purchase of crop-weather insurance, but by 1988 only 29% of the agricultural lands of the United States were insured by U.S. farmers and the program was being severely questioned (Reuters, April 10). The 1988 Drought Assistance Act with nearly $4 billion in relief payments had further eroded interest in insurance and contradicted the 1982 policy. One of the basic premises by Wheat

Belt Congressmen was "anyone hurt by this natural disaster deserves assistance." Thus, the "insurance versus relief" controversy was a major issue relating to securing special relief for the winter wheat farmers.

By April 23, the damage to the Kansas wheat crop was estimated at 48% of crop loss, and the Kansas Senators and Representatives were openly seeking special relief in deference to the "hold off" position of the Administration (Chicago Tribune, April 23).

At the same time, another form of agricultural relief but one related to the livestock sector developed. An interesting set of events began on April 25 when the Governor of Iowa requested the USDA Secretary Yuetter to: 1) open up grazing land in the set-aside program and in the Conservation Reserve Program, and 2) let livestock producers obtain cheaper feed by use of government subsidy or purchase from government grain stocks (UPI, April 25). The drought effects on livestock feeding were seen in Washington as a problem easier to solve than the regional wheat problem, and the Administration acted quickly. On the next day, April 26, the USDA announced that if a county had lost 40% or more of its pastures, it "qualified" and could cut the hay on idle land or graze livestock on idle land (Reuters, April 26).

On April 27, the USDA announced that farmers could also purchase surplus grain from the Commodity Credit Corporation at half price. Secretary Yuetter also established a Drought Task Force to monitor the drought with the assignment to evaluate the question of extending relief payments because of 1989 crop losses (AP, April 27).

Concern over the losses to wheat plus those to other crops reappeared in the Congress in early May. This followed the USDA's announcement on April 27 which had optimistically noted that the U.S. <u>total</u> wheat harvest for 1989 would be up from last year when production had dropped to 1.8 billion bushels; USDA was predicting 2.1 billion bushels as a national crop in 1989 (AP, April 27). Regardless, in early May, Wheat Belt legislators reacted and began to seek a drought relief plan much like that written in 1988 (UPI, May 3). Hearings about the crop losses were held by Congressmen in Texas and Kansas, and Senator Dole stated that the cost of a 1989 agricultural drought relief plan would be approximately $350 million (UPI, May 4). He further indicated that this cost would be offset by much smaller crop subsidy payments because of the lower wheat yields. USDA responded on the same day (May 5) indicating they were "watching the weather conditions."

On May 11, Secretary Yuetter of USDA surprisingly announced that farm drought relief, like that in 1988, "may be necessary" in the winter wheat areas (Chicago Tribune, May 11). The degree of estimated loss in the Great Plains was 21%, with Kansas down 37%.

Weather scientists of NOAA issued a prediction on this date that the drought was expected to continue in Kansas and the High Plains (News-Gazette, May 11).

The other major form of "agricultural relief under consideration," the assistance allowed the livestock producers through use of set-aside areas for grazing, grew. On May 9, USDA announced that emergency grazing had been permitted in 158 counties in Iowa, Kansas, Missouri, Nebraska, New Mexico, Texas, and California (UPI, May 9). By May 16 (7 days later), grazing land relief had been extended to 323 counties (UPI, May 16a).

By mid-May, several governors brought their states into the drought debates. On May 16, the Governors of Kansas, South Dakota and North Dakota asked Congress for help in passing a drought relief bill (UPI, May 16b). Congress agreed (UPI, May 16c). On May 22 the Governor of Wisconsin convened a Drought Task Force because of the severe damage to the alfalfa crop (UPI, May 24), and the Governor of Illinois assembled his Drought Task Force on May 24 (Chicago Tribune, May 24). Iowa established for livestock producers, an emergency water plan (UPI, May 22b).

On May 24, Secretary Yuetter further relaxed the rules on use of conservation lands for grazing (Reuters, May 24). The new ruling allowed all conservation lands to be eligible in states (not counties) where 75% of the counties had been locally designated as "drought stricken." By June 5, the USDA announced that 582 counties in 16 states had been approved for "aid"; that is, permission to harvest hay and graze livestock on harvested acres (UPI, June 5a), and this grew to 678 counties by June 12 (UPI, June 13).

On May 25, the House of Representatives passed a $1 billion relief bill extending the provisions of the 1988 relief act (Reuters, May 25). That is, a fanner would receive 65% of the target price of a crop if his crop losses were greater than 35% of his normal production. The Bush Administration said "no"; indicating that it was too soon to act on relief. Also, Secretary Yuetter wanted an agreement with Congress that after 1989, only crop insurance would be used as a "disaster protection." This reawakened the issue over the crop insurance vs. disaster relief approaches with its own internal conflicts within Congress. Yuetter toured the drought areas in late May presumably to show concern of the Administration (UPI, May 30).

The House Committee approved the drought bill on May 26 with the USDA indicating disapproval. The House passed the $1 billion aid bill on June 27 (AP, June 27).

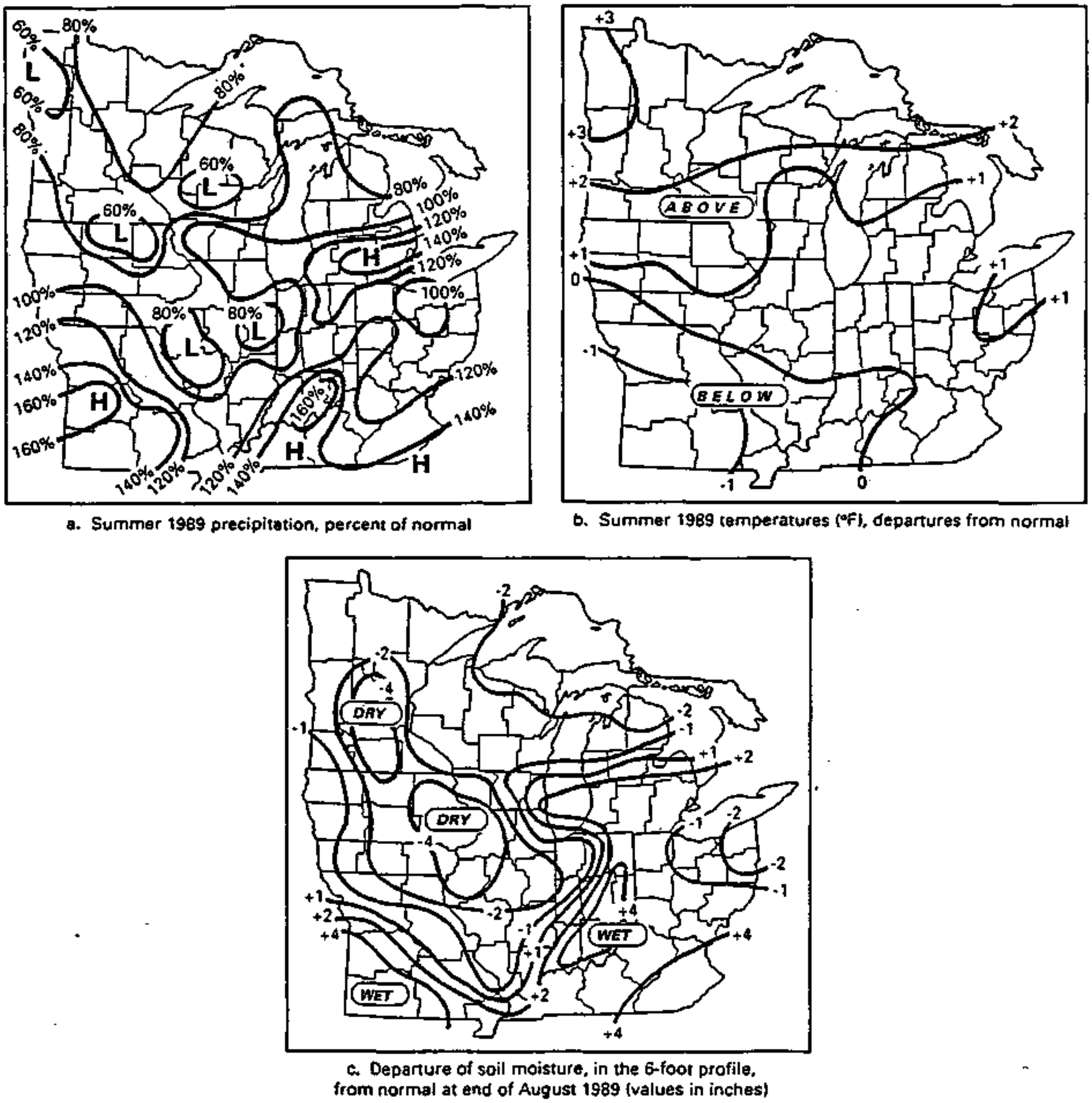
Wheat Belt Senators were also trying to extend the 1988 Farm Relief Bill within the Senate. Senator Bond (MO) asked USDA for relief aid beyond the grazing acreage and haying privileges. He also called for a change in the crop insurance program (UPI, June 12).

On June 2, Senator Leahy, Chairman of the Agricultural Committee in the Senate, indicated the Senate would "wait" before entertaining legislation on farm relief (AP, June 2). He indicated that further monitoring of the weather and other crops was needed. An important debate that was present concerned whether the 1989 drought relief action should include "all crops" or just winter wheat. The Senate resolved its internal differences in mid-June; it unanimously passed a $300 million rural development program, and Senators Leahy and Lugar (the ranking members of the Agricultural Committee) agreed to "act on July 19 on drought relief (AP, June 14). Senator Dole was expected to seek only relief for winter wheat growers, but others would want help for livestock producers (Chicago Tribune, June 28). On June 28, President Bush announced that he would oppose the proposed Drought Relief Bill because it contained too many crops under its "umbrella" (AP, June 28). Iowa leaders continued to criticize the USDA's drought policies (UPI, June 27).

As the summer of 1989 continued, other extreme weather conditions around the nation began to detrimentally affect the "summer planted crops." Pressures appeared in Washington from rice and cotton farmers in the south where more than double the average spring and summer rainfall had occurred, producing overly wet soils and flooding, and obvious future crop reductions due to poor yields and decreased planting. Extreme wetness and below normal temperatures in the eastern Corn Belt during April, May, and June delayed and then canceled considerable corn planting, decreasing the USDA's expected planted acreage from 73 to 71 million acres.

Furthermore, continuing dryness in the western Corn Belt during the spring and summer of 1989 likely would create below average yields in both corn and soybeans. By mid-July, the Governor of North Dakota had declared that state a drought disaster area with expected losses of greater than $0.5 billion due to spring wheat damages (Reuters, July 17). These major weather impacts from the 1989 drought and overly wet conditions increasingly entered into Congressional debates and the Administration's policies that were evolving during the summer of 1989, and in particular, on the dimensions of agricultural relief for U.S. farmers.

By early July, the USDA's posture on the seriousness of the continuing drought and the overall impact of the drought of 1988 and that of 1989 was of interest. Secretary Yuetter analyzed the drought depleted stocks and concluded that we have a "comfortable supply" (Bureau of National Affairs, July 5). He further announced that "1989 is a strange weather year" (Figure 9). Also in early July, the USDA, based on its July 1 crop estimates announced two important facts. First, that the expected 1989 corn production of 7.85 billion bushels as estimated in March was reduced to 7.45 billion bushels (Reuters, July 12). No decrease in soybean production was seen at that time. Second, Secretary Yuetter of USDA indicated that for the first time the government might have to "expand" its assistance to



a. Summer 1989 precipitation, percent of normal

b. Summer 1989 temperatures (°F), departures from normal

c. Departure of soil moisture, in the 6-foot profile, from normal at end of August 1989 (values in inches)

Figure 9. The patterns of departures of summer (June-August) precipitation and mean temperatures from normal, and departure of soil moisture values from normal at end of August for the Midwest (Midwestern Climate Center, 1989).

farmers due to losses to several crops in 1989, repeating that it is "an unusual weather year." By these statements, the USDA had shifted its policy from a wheat-only relief to that to include many other major crops including rice and cotton (AP, July 12). By mid-July, the Governor of North Dakota had declared the state a disaster area due to the drought damage to the spring wheat, with the winter wheat loss in Kansas being estimated at $1 billion (Los Angeles Times, July 16). Secretary Yuetter then announced in mid-July the need to provide relief to farmers that had experienced too much rain (Farm Week, July 17a).

In the meantime, drought assistance to livestock producers continued to expand. The USDA announced in mid-July that drought aid for emergency hay and grazing of livestock had been extended to 925 counties and embraced 20 states including Pennsylvania (UPI, July 17). The livestock feed assistance program had expanded to 250 counties in 14 states, and 387 counties in 16 states had been approved for haying and/or grazing on Conservation Reserve Lands.

The Senate finally came to grips with the agricultural relief act. The Agricultural Committee of the Senate met in mid-July and found itself with a politically-aligned debate over the dimensions of the relief bill. Republicans, led by Senator Dole of Kansas, wished to minimize the extent of the emergency aid, and Democrats wished to extend it beyond the bounds that the Republicans and Bush Administration wanted (AP, July 20). By July 25, the Agricultural Committee of the Senate had approved a Drought Relief Bill, with 10 Democrats voting yes and the 9 Republicans voting no (UPI, July 25). This relief act provided approximately $1 billion for farm aid.

The Senate continued to debate the dimensions of their version (not the House version) of the Agricultural Relief Act of 1989, the Administration spoke. Secretary Yuetter told the Governor of Iowa that 1) corn growers should be included in the assistance, and 2) that relief for soybean losses and other crops remained uncertain (News Gazette, July 25a). Yuetter further announced that the "pie" is set at $870 million for relief. In this fitful time, Senator Leahy, Chairman of the Agricultural Committee, indicated that he wanted the relief bill agreed upon by both the House and Senate by August 4, the day before the Congress adjourned for its one-month summer vacation. The Administration threatened to veto any act if it exceeded $1 billion. Basically, the Republicans only wanted relief to go to farmers who had raised crops covered by "government price support program," that is, wheat, corn, rice, and cotton. This did not satisfy the Democrats who also wished to include soybeans and other damaged crops. Senator Dole announced that he would scuttle any bill over $1 billion and that the Democratic version amounting to $955 million was too high. The Senate Agricultural Committee met on July 25 and the Republican members agreed to accept soybeans as well as program crops for relief, but the Committee then disagreed over the levels of coverage for each crop (News Gazette, July 26).

Agricultural interests around the nation became highly sensitized to the political discord which was seen as jeopardizing the chances for enacting a relief bill (Farm Week, July 31b). The American Farm Bureau supported the Democratic version of the bill and did not desire discrimination among producers of different crops.

In early August, the Senate resolved a parallel problem, the Rural Development Program (News Gazette, August 3). In an effort to complete its work before its adjournment on August 5, the Senate Agricultural Committee developed a "package" on August 2, and approved a 1989 Drought Relief Act amounting to $885 million seen as "fair to all" (News Gazette, August 3). On August 4, the fitful day before the Congressional vacation, the House and Senate agreed to a mixed relief package set at $900 million by resolving that relief would go to producers of all crops, but that payments be set at varying levels (News Gazette, August 5). Secretary Yuetter indicated that the approved level of $900 million was "acceptable." The bill that the House and Senate through compromise agreed upon provided the most extensive protection to farmers who had participated in federal farm programs, and to those who had federal crop insurance in 1989. The five specific levels of payments were set as follows:

a. Those in federal programs and with crop insurance would receive 65% of the target price on all crop losses greater than 35% of their normal production.

b. Those in federal programs but **without** crop insurance would receive payment for all crops when the loss exceeded 40% (not 35%) as above.

c. Soybean growers (not a program crop) would get 65% of the target price when their crop losses exceeded 45%.

d. Producers of non-program crops would get 65% of target prices if losses exceeded 50%.

e. Farmers who produce program crops but did not participate during 1989 would get 65% target price with losses greater than 50%.

The bill importantly allowed for losses regardless of whether it was due to the drought or because of the extremely wet conditions that also developed in 1989.

President Bush signed the 1989 Farm Relief Act into law on August 15, almost exactly a year after President Reagan signed the 1988 Farm Relief Act. However, the 1989 Relief Act provided approximately $1 billion for assistance, only 25% of the $4 billion provided in 1988. This is one measure of the difference in the drought impacts between the two years.

SUMMARY

In conclusion, the federal policy conflicts centered around several issues. The first involved differences within Congress and also between some members of Congress and the Administration. It concerned the use of drought relief versus use of the all-weather peril insurance program. Earlier agreements had broken down on this question essentially because farmers had not widely used the insurance program. This attitude had been further enhanced by the issuance of sizable farm relief payments in 1988.

The second issue concerned interest in the provision of major federal relief assistance for spring crop and livestock problems. This included, during the spring of 1989, a difference with the Administration providing relief for livestock growers (which of course did not involve financial resources) versus not wanting to provide financial relief for the wheat farmers, an interesting contrast. In both cases, there were regional interests during the spring of 1989 combatting the so-called "national interest," both in Congress and in the Administration.

The third issue and most critical area concerned how to provide relief payments for all crop losses in 1989. The questions debated included whether to rewrite a new generic relief act for 1989 or to extend the 1988 Farm Relief Act with more funds, waiting to be more sure of the extent of loss after harvest. A central question focused on what crops to cover in the 1989 Relief Act, just wheat (initially), then just government program crops, and then all other damaged crops (Farm Week, July 3). This issue also dealt with crop problems stemming from too much precipitation found in the south (rice and cotton) and in the eastern Corn Belt.

The government handling of the drought (and the other weather extremes) of 1989 revealed other major interesting policy issues and their causes. It was obvious that the expectations and monitoring for the drought of 1989 were inadequate, as in 1988. Great uncertainty was presented about the status of the drought by meteorologists over whether the drought would continue, redevelop, or terminate in 1989, and if present, how severe it might become. These issues, coupled with constant uncertainties about the dimension of drought's effects on crop production were important in causing conflict within Congress and Administration over how to address and manage the drought problems.

Another interesting aspect of agricultural policy revealed in the government actions includes an interesting shift in Administrative attitudes. During the spring of 1989, the views of the Administration, expressed largely through the USDA, were ones of cautious optimism about no drought in 1989 with a tone of downplaying its potential, particularly of loss to summer crops. As conditions worsened during May, June, and July, the position of the USDA shifted from relative optimism to realism with admissions by July that the nation not only had drought damage to the winter wheat crops of the High Plains, by then to corn and soybeans in the western Corn Belt, and then to spring wheat in the northern High Plains. The USDA announced by late August that "lingering drought" had continued to reduce crop production and reduce U.S. grain reserves (News Gazette, August 25b). Reasons for the earlier optimistic outlook could be credited to several factors including wanting to present a bright outlook about future U.S. grain exports to foreign users, and to a general sense of optimism around a new crop year, plus use of long-range weather outlooks that downplayed and underestimated the dimensions of the continuing spring and summer 1989 drought.

Importantly, the agricultural reactions to the drought of 1989 that affected the winter wheat producers, the livestock and hog producers, and then the corn, soybean, and spring wheat producers, again reflected a total focus in the Administration and in Congress of "crisis management of drought." **The lessons of 1988 had not been learned.** The need to establish and maintain a high-level Administration Task Force on Drought had not been realized in 1988, and if such a group had been present it might have alleviated certain of the agricultural problems.

Another issue that began to appear along with the drought problems of 1989 related to future agricultural policies. The new (1990) Farm Bill which will be constructed during the next 12 months (post August-1989) will contain many controversial issues. One of those created by the drought of 1988 and 1989 is related to the issue of use of crop insurance versus disaster relief (Farm Week, July 3). The Illinois Farm Bureau suggested that all insurance be moved to the private sector. Another future policy issue from the drought of 1989 will be the corn set-aside levels. The USDA announced (Farm Week, July 24c) that the maximum value in 1990 would be less than 12.5% (it was 10% in 1989). Importantly, on July 3, 1989, the USDA had forecast a set-aside in 1990 greater than 12.5% of lands in corn, but this had shifted by late July (with new and larger crop loss estimates) to less than 12.5%.

Another area of national policy effects ensuing from the droughts of 1988 and 1989 (and possible future drought), relates to national grain surpluses with their great importance to U.S. commerce and to global food supplies. The USDA's 1988-89 policy relating to U.S. grain production and surpluses, including exports in 1989, was based on a "non-drought" scenario for 1989. As noted, it was essentially optimistic and based on an expectation that the weather would return the U.S. to "normal agricultural production." It did not and the temporal differences in the USDA's expectations for corn production and surpluses are revealed in Table 2 below.

Table 2. USDA Estimates of 1989 corn crop and available surpluses.				
	Fall 1988	March 1, 1989	July 1, 1989	August 1, 1989
Production (billions bushels)	-	7.85	7.45	7.35
Acres (millions acres)	-	73.3	727	65.15
Yield (bushels/acre)	-	114	113	112.8
Stocks (billions of bushels)	4.25	2.0[1]	2.83[1]	1.68[1]

[1]Expected by Fall of 1989

This reveals how the expectations for production and in turn surpluses rapidly fell. To interpret the surpluses and production figures, note that the U.S. annually utilizes 7 billion bushels of corn.

Wheat production also fell with winter wheat yields reduced 35% in Kansas and Nebraska and spring wheat reduced by drought in the Dakotas and Montana. The 1988 drought brought U.S. production down to 1.81 billion bushels, and end of August estimates for 1989 indicate 2.04 billion bushels for 1989 (News Gazette, August 25b). This compares to annual usage of 2.3 billion bushels. Exports will fall by 10% and predicted U.S. stockpiles on June 1, 1990 are for 474 million bushels, the lowest since 1975. The world's stocks of wheat are now the lowest since 1975.

Several events, and some foreseeable, occurred to defeat the USDA's optimistic expectations for 1989 weather and crop yields by the USDA. First, the drought in the western Corn Belt was sufficiently severe, coupled with the loss of deep soil moisture due to the drought in 1988, to lead to severe crop conditions and one that was climatically predictable by January 1. Climatological probabilistic outlooks from NOAA issued in December 1988 indicated that this area had only one chance in 100 of escaping drought during the first 6 months of 1989. Second, Corn Belt farmers who were inherently aware of their low soil moisture carryover, tended to plant lower (less dense) stands than average and this decreased in-field yields. Third, the extreme wetness and low temperatures in spring and June in eastern Indiana and Ohio decreased the USDA's expected increases in planted acreage for 1989. Following the 1988 drought and the low production, coupled with the relaxation of the set-aside lands restrictions to 10%, USDA expected to get increased national production. However, increased planting was not as great as expected, due to the wetness in the eastern Corn Belt, and due to the fact that many farmers simply could not afford to increase planting due to their low income from 1988. Fourth, corn yields were hurt throughout the Corn Belt by "carryover problems" from herbicides used on soybeans in 1988. The low rainfall of 1988 caused these herbicides to remain in the soil and these in turn damaged the 1989 corn (Farm Week, July 3).

Although the national soybean surpluses were relatively lower by the end of 1988 than were corn (3 months supply), the production and surplus supply problems of soybeans during 1989 were less than corn for three reasons. First, the hot, dry conditions in the western Corn Belt that affected corn in June and July did not affect bean plants as much as corn. Second, farmers unable to plant corn in the eastern Corn Belt because of the wetness, shifted to beans because they were a later plant crop. Finally, Brazil had a very large soybean crop during 1988-1989 and this production helped provide an abnormally large percent of global bean needs, reducing the demands on U.S. production.

TRANSPORTATION

A major impact of the 1988 drought, with greatly reduced streamflows on the Ohio and lower Mississippi Rivers, was to impede and reduce transportation by barges. These effects were primarily during June, July, and August 1988, and they were associated with shifts in shipping to certain railroads. A major beneficiary in 1988 was the Illinois Central Railroad which has north-south connections between Chicago and New Orleans, primary ports for export shipments of corn and soybean meal (News Gazette, March 5d). These problems led to adjustments and to careful monitoring and predictions about river transportation conditions in 1989.

On January 21, Arthur Daniel Midlands (ADM), one of the nation's primary grain handling companies, purchased 14.6% of the Illinois Central Railroad at a price of $36 million (News Gazette, January 21a). The action was credited to the effects of the drought. ADM is a major shipper of grain and grain products and owns a grain-hauling barge company operating on the Mississippi River system. This action was reportedly aimed at giving it greater transportation versatility.

It was announced in early March that the railroads had moved 4.9% more carloads of grain in 1988 than they had in 1987 (News Gazette, March 5d). The Illinois Central Railroad had 40,000 more carloads handled during the last 7 months of 1989 due to drought. However, the barge problems of 1988 had hurt certain area railroads such as the CM&W and Norfolk Southern Corporation which primarily serve as feeder lines to the barge ports. A problem facing both the railroads and barge companies in 1989 was the decreased U.S. grain stocks (used in 1988 to meet U.S. exports demands) and lowered winter wheat yields.

Collectively, this meant reduced shipping.

On March 1 the National Weather Service announced that the Mississippi River level at Memphis was up, ranking as the highest level in four years (News Gazette, March 1). They also announced that the Missouri River was low and was already negatively affecting the movement of barge traffic. In early March, the American Waterway Operators Association indicated optimism for average barge shipments in 1989, an action attempting to positively affect plans of various shippers (the waterways versus railways issue). The Association had estimated their 1988 losses at $200 million during 1988, but chose not to pursue a definitive follow-up analysis of actual losses in 1989 (News Gazette, March 5d).

Examples of changes in costs for shipping were provided for a major river port along the Illinois River at Ottawa, Illinois. The cost of shipping a bushel of corn from Ottawa to New Orleans was 19 cents in 1987, but in 1988 it was increased to 46 cents per bushel. Illinois grain shippers were optimistic about good river transport conditions throughout 1989. The optimism was being generated by the high flows of the Ohio River, a result of heavy spring and June rainfall in Kentucky, Ohio, and Tennessee. However, on May 1, the Missouri River flows were still well below average and it was announced that navigation on that river would be curtailed during 1989 (UPI, May 1). Figure 3 reveals the extent of severe drought conditions covered 44% of the Mississippi River Basin during May 1989, and this was the fourth largest drought in May since 1895 (only Mays in 1931,1934, and 1954 exceeded 1989).

Optimism over river transport turned to pessimism by late May. On May 29, the USDA announced that reduced flows on the Mississippi River would cause bottlenecks for grain shipment by early fall of 1989 (News Gazette, May 29). The Missouri River levels during January-April 1989 and those on the lower Mississippi were well below those of 1988 for the same period. By the end of April, the Mississippi River level at St. Louis was 13.5 feet, 6 feet below its average.

By August 1, grain prices were down and grain stocks in the central U.S. were largely depleted. Barge shipping rates had been reduced below profit-making levels and 20% of all barges were not in use. The Mississippi River near St. Louis was sufficiently low to provide occasional problems for barge movements. The central Mississippi and Illinois Rivers were both low and very dependent on frequent summer rains to sustain sufficient flow for barges. The prolonged drought led the Corps of Engineers (COE) to decide to close navigation on the Missouri River one month early (on November 1, 1989), and the COE further announced that reservoir levels (in the basin) would be lower at the end of 1989 than the end of 1988 (UPI, August 10).

WATER SUPPLIES

As the United States entered 1989, water supply drought concerns were evident (see Fig. 1c) in the northeast (Pennsylvania, Delaware, New Jersey, New York, and north to Maine); in the western Corn Belt; and in California-Nevada (News Gazette, February 6).

Deficient precipitation in the northeastern United States during the winter of 1989 increased concerns in that area (News Day, May 2). The Delaware River Basin Commission issued a drought warning on January 17, automatically reducing the amount of water that northern and central New Jersey could withdraw from the basin. Then, a drought watch was adopted in the New York metropolitan area (Northeast Regional Climate Center, March 1989). Reports from the Susquehanna River Basin in central Pennsylvania indicated that state officials found serious ground water deficiencies and declared a drought watch. On April 1, the mayor of New York announced a drought emergency, setting strict limits on business water use. Heavy precipitation began falling in late April throughout the northeastern United States (Northeast Regional Climate Center, July 1989). Several New York area reservoirs were 80 to 100% filled by mid-May, and the water supply drought conditions of the northeast were alleviated (News Day, May 2). Several areas received from 120 to 155% of normal precipitation during the late spring, and by June no drought was present as shown in Figure 1d (Heim, 1989).

The water supply (hydrologic) drought in the Midwest was severe in the summer of 1988 and continued to be severe in northern Missouri, southern Iowa, and western Illinois during early 1989 (Los Angeles Times, May 14). Some problems related to expanded irrigation in Illinois during 1988 which had depleted ground water reservoirs (News Gazette, January 21c). The acreage irrigated in Illinois expanded by 15% in 1988 and led to local controversies over water pollution due to refiltration of farm herbicides, pesticides, and fertilizer.

Water supply problems deepened during the late spring, particularly in northern Missouri and Iowa. Several communities in northern Missouri reported water supply shortages by May 1 as well as problems with rural water supplies (UPI, May 1). Iowa communities and farmers were short of water (Washington Post, May 21). Several Illinois water supply systems which had experienced difficulties in meeting needs during the 1988 summer period, announced plans to develop new filtration systems, to enlarge storage, and to extend water lines (News Gazette, May 4). By the end of June 1989, three Illinois communities were still rationing water (Illinois Water Survey, July 1). These problems continued through the summer (News Gazette, August 20).

In Iowa, April newspaper headlines effectively proclaimed that "the drought of 1988 continues" (Los Angeles Times, April 14). Numerous ground water problems were noted, and water was being hauled by the National Guard to nine Iowa communities during April, May, and June. The Iowa legislature voted funds to help in developing pumping stations to help alleviate livestock water shortages. Communities in Missouri were in trouble and were seeking new sources while using severe conservation (UPI, May 1). Missouri communities continued to have problems throughout the summer and farmers were driving up to 100 miles daily in July to obtain water for their cattle (UPI, July 23).

The more severe 1989 drought area in the High Plains occurred in areas that were not in severe agricultural drought in 1988. In 1989, Kansas, Nebraska, and Colorado (see Figs. 5-6) were hard hit, as opposed to the Dakotas and Montana being the hardest hit in 1988. The 1989 drought in the central and southern High Plains also affected water supplies for livestock, children, and crop producers. The dryness led to very slow growth of pastures, requiring use of supplemental feed. In some areas, livestock water supplies were very short, and livestock producers were selling cow-calf pairs at above normal rates in spring (Financial Times, May 19).

Agricultural irrigation, which is widely practiced in many of the 1989 drought affected areas of the High Plains, was impacted by the 1988 and 1989 droughts. Producers with sprinkler irrigation watered their crops prior to fall emergence, a very unusual practice, in an effort to provide water then lacking in the topsoil for the winter wheat. Nebraska estimates placed 1989 irrigation costs at least 10% above those of 1988 (High Plains Climate Center, May 1989).

The drought in the far west was severe during 1987-88 in portions of California and the northwest (News Gazette, February 26). Generally deficient precipitation during the 1988-89 winter, particularly in Nevada and central-southern California, helped sustain drought-like conditions in those areas (Fig. 4). Growing precipitation deficiencies, coupled with above normal temperatures elsewhere in the southwestern United States (Arizona, New Mexico, Utah, Colorado) brought ever deepening drought conditions during the spring and early summer of 1989 (Fig. 1d), (Christian Science Monitor, June 2, and CAC, May 1989).

Storms in March dramatically improved northern California's water supply outlook, and federal and state agencies lifted many water delivery restrictions in April. Yet, 1989 streamflow volumes were expected to be about 75% of average in the central and northern Sierras and only 50% of normal in the south.

Portions of the northern Great Basin continued to experience a third year of deficient water conditions (Western Regional Climate Center, August 1989). The spring of 1989 had below average runoff as mountain snowpacks were quickly removed as a result of very high temperatures in April. The northern third of Utah experienced extreme drought conditions during the spring of 1989, and municipal water supplies became quite low with many Nevada reservoirs being at or below 50% of average.

Thus, during the 6-month period of January-June 1989, the water supply drought in the United States deepened in the southwestern United States, covering an area bounded by central California, Nevada, Utah, Colorado, and areas southward and westward (see Fig. 1d). Water supplies in the Missouri River Basin were also deficient (CAC, July 1989), affecting river transport as well as water supply at several communities, with shortages at rural sites in the High Plains and western Corn Belt (News Gazette, May 29). Water supply conditions were average or above elsewhere in the United States (CAC, May 1989).

The agricultural and water supply droughts by September 1989 included: 1) areas in the west central Corn Belt; 2) areas in the northern and central Great Plains; and 3) most of the southwestern United States including the Great Basin, the southern half of California, and Arizona and western New Mexico. The major U.S. drought that began in 1987 was well developed and in its third year.

ENVIRONMENTAL EFFECTS

One of the greatest areas of speculation about effects of the drought of 1988 was in the area of the natural environment. Considerable concern had been expressed in 1988 about long-term effects to private and public forests, to water quality, and to fish and wildlife. Unfortunately, these effects in many cases were not well monitored during 1988 and were only being crudely estimated. Many relationships between extreme weather conditions like droughts and parts of the natural ecosystem are poorly understood, and in general, effects could not be adequately assessed during 1988. However, various impacts and adjustments relating to environmental effects became more apparent during the winter and spring of 1989. The 1988 fires in Yellowstone Park had been excessive and their management became a national issue. Adequate 1989 rainfall had helped regenerate growth in the Park (News Gazette, August 30a), but debates over how to manage the U.S. forest resources continued (Conniff, 1989).

One sign of effects in 1989 occurred in January when the state of Missouri restricted its duck hunting season and areas, detrimentally affecting its tourist industry, to protect the reduced number of ducks (News Gazette, January 21b). A major article in Sports Illustrated (March 13) entitled, "A Climate for Death," reported on various impacts including very negative effects on wildlife populations including turtles and ducks (in the northern

Midwest), with populations of ducks down 38% on the Pacific flyway. Reports of decreases in the buffalo and elk herds of the northern Rockies were also provided.

Another environmental effect was predicted in mid-April 1989. This was for increased pest populations during the spring and summer of 1989 due partly to the 1988 drought, as well as to the mild winter and low snowcover in the Midwest (Chicago Tribune, April 16). Also, winter kill of evergreens was increased partly as a result of the drought, with an increase in canker disease which attacks the stems of woody plants and trees (News Gazette, June 10). The summer of 1989 produced sizable Midwestern and northern mosquito populations, seen as a result of the 1988 drought (News Gazette, June 28). Fears of an increase in encephalitis caused by the large mosquito population also appeared (News Gazette, August 30b).

Assessors announced in May that there was considerable shrub and tree damage across the Midwest as a result of the 1988 dryness (UPI, May 8). The health of many plants had been weakened by the drought, plus by the wide temperature swings of the 1988-1989 winter. Young fruit trees, 1 to 2 years old, were noted to be dying in orchards across western Michigan, resulting in the loss of millions of dollars (UPI, May 8).

The drought of 1988 resulted in enormous wildfires across the central basin and Pacific northwest. Controversies raged over the amount of environmental and economic damage to public and private forests, but the damage was very large. The sustained dryness of 1988-89 in parts of California, Oregon, Idaho, and Wyoming, plus new and deepening drought in Utah, Colorado, Nebraska, Arizona, and New Mexico a (9-state area) led to an early resumption of wildfires in late June 1989 (News Gazette, July 8). By July 10, 1989, 44 wildfires were burning uncontrolled and two persons had been killed (News Gazette, July 11). Nearly 40 homes were destroyed in Colorado and fires raged over 200,000 acres by mid-July (News Gazette, July 12).

Fire problems continued into August. By August 1, 20,000 fire fighters were dealing with fires in Idaho, Washington, Oregon, and California, and a reported 175,000 acres had been burned in these four states (News Gazette, August 2). After a short period of cool weather which aided fire fighting in certain regions in early August, fires had also spread in Montana. Severe fires in the Boise National Forest were being fought, and it was reported that $36 million had been lost in the forestry sources there (News Gazette, August 4a). By August 5, 225,000 acres of fires were burning, and there had already been 1.4 million acres burned (News Gazette, August 6). Army troops had been added to the fire fighting force, bringing the total to 23,000.

Soil erosion had been increased by the spring drought. Windblown erosion was reported to be the worst since 1954 (News Gazette, June 20). The 1989 drought, centered in the western U.S., provided major problems for water resources and the environment.

HUMAN HEALTH

One of the major impacts of the 1988 drought and the associated heat wave during June, July, and August 1988, were the impacts of human health. It was estimated that approximately 5,000 died from the extreme heat, and many of these deaths occurred in major metropolitan areas in the central and northeastern U.S.

During the summer of 1989, temperatures across the Midwest and Northeast were generally near average, and although there were periods of extremely high temperatures, the number of days with temperatures in excess of 90°F were not excessive. This tended to minimize health impacts from high temperatures, as well as to help lessen the effects of the below normal precipitation on agriculture and water supplies. However, it should be noted that temperatures in the southwestern states were much above average throughout the spring and summer of 1989.

Temperatures in the Midwest during July 1989 became excessive. Prolonged above average temperatures during the first half of July led to illness and deaths. By July 10, three cities (Chicago, Cincinnati, and St. Louis) had opened a city-wide series of "cool centers" (AP, July 11b). On July 11, three persons died of heat in St. Louis, bringing a total there of 6 versus 25 at that time during July 1988 (AP, July 12b). High temperatures later in July were also evident along the east coast. Boston opened 24 cool shelters, the Northeast Power Pool set records for usage, and a heat alert was established in New England (UPI, July 27). It appeared that greater attention was being given in 1989 to alerting urban citizens to heat threats and the availability of cool centers than had occurred during 1988, suggesting a lesson that had been learned.

DROUGHT MONITORING, UNDERSTANDING, AND PREDICTIONS

One of the interesting aspects of the 1988 drought concerned problems over the availability of weather/drought information, and the pronouncements of scientists about the causes of the drought and its status. Information relating to the drought and its seriousness had been notably tardy in issuance in 1988. There were also claims and debates about whether the drought of 1988 had been caused by the long-predicted climate change due to the Greenhouse Effect. As will be shown, scientists continued in 1989 to provide widely differing views of the 1989 drought including its causes, severity, and possible termination.

In January 1989, a national news story indicated that the scientists had "agreed" that the drought of 1988 was not due to the Greenhouse effect (News Gazette, January 5). At a major national scientific meeting in January, other scientists announced there had been $40 million losses due to the drought of 1988 (San Francisco Chronicle, January 21). They claimed that the U.S. response to the drought was poor, and called for the U.S. to develop plans for continuing drought in 1989 (an action which had not occurred, St. Louis Post Dispatch, January 23).

Congress get in the impact monitoring issue early with Congressman De la Garza announcing (on February 2) that critical drought conditions still existed in the U.S. (News Gazette, February 2). NOAA's Climate Analysis Center had announced on January 29 that a severe drought was still present in the Great Plains and the western Midwest (San Francisco Chronicle, January 29). Another scientist proclaimed in January the high likelihood of a water supply drought in the west (St. Louis Dispatch, January 23). Events later in 1989 proved these predictions to be correct. A major news story issued on February 6 presented a national analysis of drought conditions for major U.S. areas. This indicated that the southwestern U.S. had experienced a warm and dry winter affecting insect populations and the winter wheat crop, and the western Corn Belt (Iowa, Missouri, and western Illinois) was dry as was the west, California and Nevada. However, USDA meteorologists indicated great improvement in drought conditions since 1988 (News Gazette, February 6).

Five days later, a climatologist announced that soil moisture in Illinois would recharge and that a 1989 drought in Illinois would be unlikely (News Gazette, February 11). On February 20, the senior meteorologist of the USDA announced that there would be "no serious drought in 1989" (News Gazette, February 20). This forecast failed.

At that time (late February), it was clear that moderate to severe drought existed in several parts of the nation (see Fig. 1c). The Climate Analysis Center (March 1, 1989) issued the first drought monitoring report for 1989 and it depicted widespread drought. however, some weather experts were proclaiming that the drought was not going to last, nor be on the scale of the 1988 drought. On March 3, a NOAA scientist proclaimed the likelihood for continued drought in California (News Gazette, March 3). Illinois scientists further predicted on March 5 that the drought of Illinois in 1989 was "unlikely" with continued improvements in soil moisture (News Gazette, March 5f). This openly contradicted a news story on March 4 indicating that soil moisture in western Illinois was less than existed in 1988, leading to more midwestern confusion (News Gazette, March 4).

On April 10, USDA's Chief Meteorologist announced it was premature to decide there would be a severe drought in 1989, indicating that "weather patterns of 1989 are different and better (less drought-like) than those in 1988" (Reuters, April 10). The crop effects of the extreme temperature differences occurring during the winter of 1988-89 did not appear to be accounted for in the assessment of drought in 1989.

On April 14, Iowa scientists indicated that drought conditions in their state were serious; that Iowa had never recovered from the 1988 drought, and that there was a major drought "pocket" existing across most of Iowa, western Illinois, northern Missouri, and southern Minnesota, and Wisconsin (Los Angeles Times, April 14). Weather scientists in these five states all agreed on the seriousness of the drought in this area. These views conflicted with the optimistic outlook by some weathermen at the national level.

This confusion of views by weather scientists, partly due to statements concerning areas of different scale (national vs. regional) was apparent to farmers and agribusinesses. It further eroded the credibility of the pronouncements of the atmospheric scientists. This helped feed the volatile weather market previously described (AP, May 1).

On April 26, USDA's Chief Meteorologist again issued an "optimistic" outlook on U.S. drought conditions (Reuters, April 26). He specifically indicated optimism about prospects for the crops that would be planted in the spring of 1989. (One could no longer be optimistic about the winter wheat crop, at least that in the Great Plains.) However, on May 2, a National Weather Service forecaster stated the spring outlook did not look good for ending the drought (News Day, May 2), a position in conflict with the USDA statements issued 6 days earlier. The second drought advisory of NOAA revealed an enlarging drought in the U.S. (CAC, May 1989), as revealed it figure 2.

Many local and regional stories analyzing the drought continued to be issued in May. On May 2, a national news release presented an analysis by several scientists about the cause of the 1988 drought (News Day, May 2). It concluded that the drought was not related to the Greenhouse Effect or to climate change.

Iowa scientists then announced, on May 8, that early May rains had helped some in Iowa, but that 90% of Iowa had less than adequate subsoil moisture and 32% less moisture in the top soils than needed and that drought would occur (UPI, May 8). In early May, an Illinois scientist indicated that drought was present across the northern third of Illinois (News Gazette, May 2). On May 11, High Plains scientists predicted the drought would continue in Kansas and the other parts of the High Plains (News Gazette, May 11). Climatologists in Michigan predicted on May 17 that there would be more drought in the Midwest during 1989 (UPI, May 17). Several scientists indicated that atmospheric patterns in 1989 were different than those in 1988, but disagreed over what the outcome would be for drought placement or intensity in 1989 (New York Times, May 16).

USDA meteorologists admitted that the drought in the High Plains was serious (UPI, May 18). They further proclaimed on May 21 that agricultural drought prospects for 1989 summer crops were still small, but announced that water supply (ground water) drought would persist during 1989 in certain areas (Washington Post, May 21). Illinois weather scientists continued to vacillate on drought prospects indicating it was unlikely in May (News Gazette, May 29), and then in June indicating that it would persist (News Gazette, June 19). The Illinois continuing drought situation was further reinforced by an announcement in early July that the drought was still present in northern Illinois (UPI, July 7b).

Scientists reawakened the drought-Greenhouse debates in July, with Washington-based scientists indicating that in 1989 there had been many weather extremes, and speculating that these were related to the Greenhouse Effect (News Gazette, July 15). A month later, an Iowa scientist announced the 1988-1989 drought was due to cyclical behavior of the climate caused by many factors (Farm Week, August 28c). He and another scientist provided long-range outlooks of weather into the 1990s that disagreed as to what would occur (Farm Week, August 28a).

Scientists increasingly addressed the extent of the 1989 drought during mid-July indicating that its dimensions included the western Corn Belt, High Plains, and Southwestern Untied States, and indicating the drought was bad but not as bad as 1988 (Los Angeles Times, July 16). USDA meteorologists also spoke to this issue in August indicating that there was great uncertainty over the causes of climate change (Farm Week, August 7b). The third drought advisory of 1989 portrayed continuing severe drought over nearly 40% of the U.S. (CAC, July 1989).

The summer of 1989 with its drought problems in the western Corn Belt and central-northern High Plains, and overly wet conditions in the eastern Corn Belt, ended with scientists predicting a new problem — early frost. Two private meteorologists issued late August predictions of early frost which would hurt the late maturing grain crops (Farm Week, August 28a and b).

Thus, the scientific assessments and pronouncements about the causes of drought, the presence and severity of drought, and the future of drought in 1989 (and 1990) offered a wide variety of contrasts and conflicting scientific options, as they had in 1988. This led to uncertainty amongst resource managers and policy makers ("who does one believe?"). Farmers in Illinois suffering from drought in late August 1989 openly complained about earlier 1989 forecasts that indicated a 1989 drought was unlikely (Farm Week, August 21a).

The National Climatic Data Center had issued (in December 1988) a climate-based outlook for conditions during January-June 1989. The outlook indicated the precipitation needed to end the drought, plus the probabilities based on historical data, of receiving sufficient precipitation to end the drought. Maps of these are portrayed in figure 10a and 10b. Figure 10c presents the actual precipitation, expressed as percent of average, received during January-June 1989 in the central U.S. This shows that the driest area, that with less than 80%, exists where the probabilities indicated drought was likely to persist during the first 6 months of 1989. A few areas with a 1-in-10 chance in Indiana and Ohio did get sufficient rain (>20 inches) to escape from drought. All Midwestern areas with only 1% chance of drought termination remained in drought. Inspection of figure 9c reveals the summer continuance of drought in the severe areas predicted for January-June. The important point is that climate-based outlooks issued in 1988 of conditions 6 months ahead were capable of estimating the continuation of drought in most regions of the central U.S. Unfortunately, few decision makers were aware of this and several forecasters issued predictions during spring that disagreed with these climate-based outlooks.

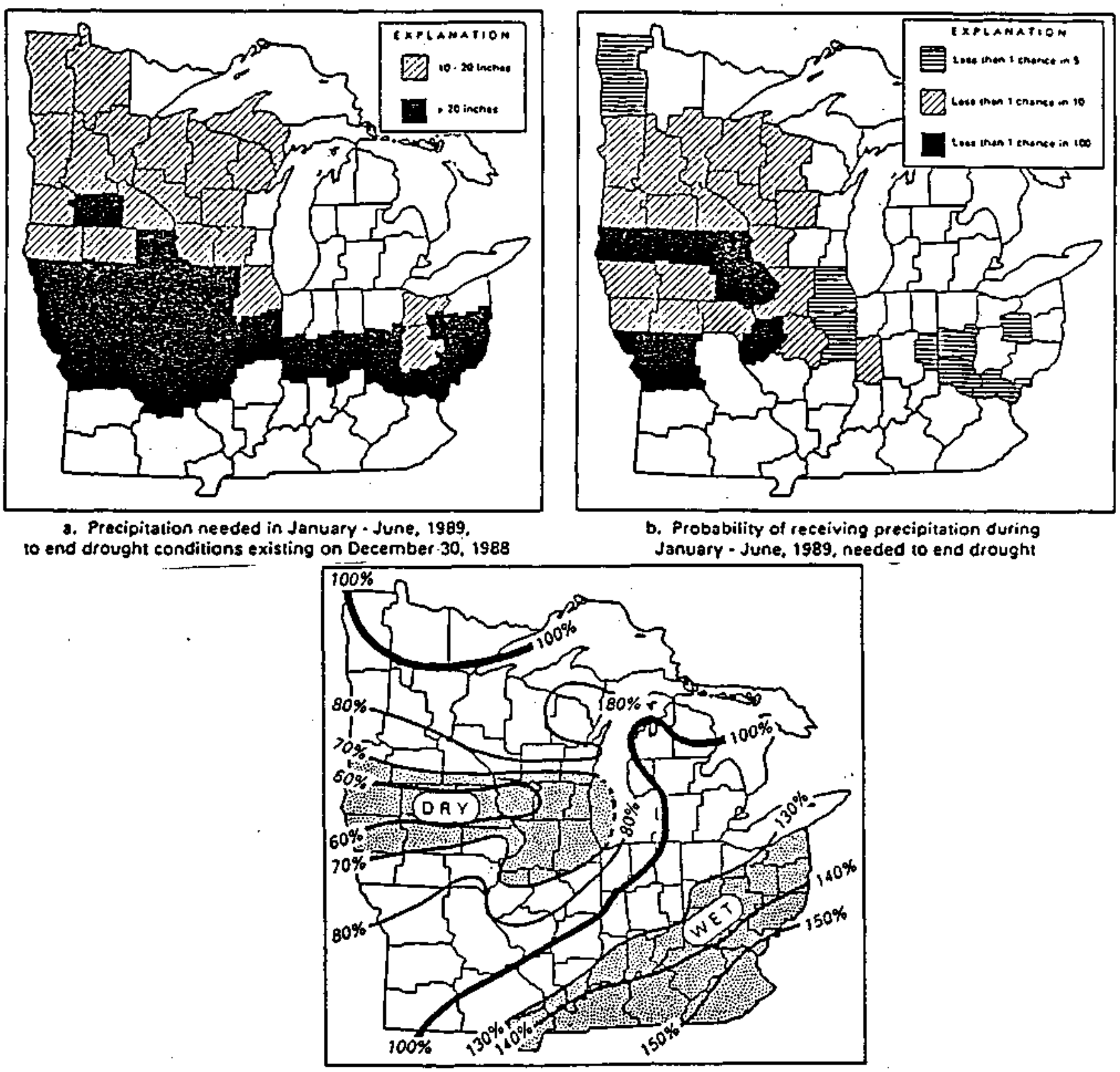
FURTHER ASSESSMENTS OF LOSSES FROM THE 1988 DROUGHT

Several assessments of the economic effects, as well as environmental effects, of the 1988 drought were made in 1988. These, of necessity, consisted of early estimates. With the passage of time, better estimates of the losses and costs became available.

On January 9, the USDA indicated that the corn losses from the 1988 drought were slightly less than expected (News Gazette, January 10). In November they had estimated 1988 corn production at 4.9 billion bushels, but the January final figure was 5.5 billion bushels of corn, still 30% less than in 1987. The yields of soybeans nationally were 1.5 billion bushels, with no change from their November estimates, but down 20% from 1987. At a national scientific conference, scientists assessing the 1988 drought reported that national drought losses amounted to nearly $40 million and that the U.S. response to the drought had been generally crisis management and often ineffective (St. Louis Post Dispatch, January 23).

By early March, it was apparent that the national sales of weather insurance were going to be much greater than in 1988 (News Gazette, March 4). The increased sales were 100 to 200% more in parts of the central United States.

On March 4, the USDA indicated that the national surplus of corn would be 1.7 billion bushels, greatly reduced from the 4.9 billions bushels in 1986 (News Gazette, March 4). The soybean surplus in March was 140 million bushels, as compared to 536 million bushels in 1986. However, great attention was paid to the fact that more acres were being planted in both crops in 1989. USDA expected an 8 to 12% increase in planted corn acreage in 1989 due to removal of set-aside restrictions (News Gazette, March 4). This was not accomplished due to the wet spring conditions in the eastern Corn Belt (UPI, June 16). Final grain production figures for the United States in 1988 were issued on April 7, indicating an overall 26% reduction. The amount of acres in corn, as assessed in June, was 1.5 to 2 million acres less than the USDA had forecast (73.3 million acres in March, Farm Week, June 26b).



a. Precipitation needed in January - June, 1989, to end drought conditions existing on December 30, 1988

b. Probability of receiving precipitation during January - June, 1989, needed to end drought

c. Jan 1 - Jun 30, 1989, precipitation expressed as percent of normal

Figure 10. Climate-based probabilities for January-June 1989 precipitation in the Midwest and the actual precipitation received, as the percent of average (National Climatic Data Center).

Continuing effects of the 1988 drought, and partially integrated with the 1989 effects, were being realized during July and August 1989. The USDA announced that U.S. supplies were at the "comfortable level" (Bureau of National Affairs, July 5). The status on national crop supplies were announced as follows: corn down 41% from 1988; old wheat down 45% from 1988 (and the lowest since 1976); soybeans down 29% from 1988; sorghum down 31% from 1988; barley down 39% from 1988; and oats down 12%. Secretary of Agriculture indicated that the U.S. had three months supply of wheat and that production would be sufficient to meet our export demands. The USDA also indicated that "these higher than expected inventories of grain during mid-1989" should help reverse the recent increases in food costs. The annual corn use is 7 billion bushels and the U.S. had 4.25 billion in the fall of 1988 (302 billion soybean) and this was now predicted to fall to 2 billion bushels of corn in the fall of 1989 (125 billion bushels of soybeans). This latter projection was based on an outlook in 1989 of 7.85 billion bushels produced of corn.

On April 13, the USDA announced that the total farm aid provided under the 1988 Relief Act was then $3.2 billion with North Dakota receiving the largest amount, $389 million. Ninety percent of the aid paid was for crop losses, and the rest for livestock (UPI, April 13). The detrimental effects of the drought caused between 10,000 and 15,000 farmers to go bankrupt. On May 8, USDA reported that the drought aid related to 1988 losses had reached $3.5 billion nearly reaching the $3.9 billion allowed under the 1988 Relief Act (UP, May 8). North Dakota with $402 million in aid was first, followed by Illinois with $368 million, Iowa with $315 million, Wisconsin with $357 million, and Minnesota- with $308 million. The total number of farmers who were recipients of aid had grown to 736,220. The 1988 payout reached $3.71 billion by early June 1989, and five states had received half the aid (UPI, June 8). By early July the 1988 drought relief had been extended to 790,000 farmers and totaled $3.78 billion (UPI, July 7a). Secretary Yuetter announced on July 16 that the drought in 1988, even with $4 billion in relief payments, had saved $6.5 billion because of the reductions in crop deficiency payments (Farm Week, July 17a). The 1988 aid level reached $3.84 billion by early August 1989 with aid given to 800,048 farmers (UPI, August 4).

Problems with the winter wheat crop of 1988-89 led to early expectations for $1 billion additional relief to be paid in 1989. Expectations for the total U.S. 1989 wheat crop (issued May 11, 1989) was 8% lower than that in 1988, with expectations that wheat exports would decline by 300 million bushels in the year beginning June 1, 1989. Crop problems related to the western Corn Belt and northern High Plains, coupled with overly wet conditions in the east and south led to the enactment of a 1989 agricultural relief bill on August 15 for $900 million to farmers with losses to any crops.

The USDA announced in late May that food prices in 1989 would be up 5.5 to 6% above those in 1988 (AP, June 3). This level was much higher than the USDA forecast issued in November 1988 for 3 to 5% increases. There was great concern over the increased costs to the beef industry due to the higher cost of feeding livestock and the difficulty in pasturelands. However, a national economic analysis of the effects of 1989 drought to winter wheat and livestock producers concluded that the broad effect would be negligible and possibly even beneficial to the U.S. consumer (U.S. News and World Report, May 15). The conclusion that the wheat losses would not increase food costs was based on a belief that the livestock problems would reduce beef prices, compensating for increased costs due to grains. Wisconsin analysts concluded that the rise in food costs in that state had risen 8.7% as a result of the drought (UPI, July 31).

Economists in analyzing the 1988 drought, concluded that the drought had dampened economic growth in the United States (Lebham-Friedman, May 8). This was reflected in the fact that personal income had increased by 6.5% in 1988 being 0.5% less than 1987 (7.0%) due to drought. They predicted that the cumulative effects of the drought of 1988 and 1989 would dampen personal income growth even more in 1989. Industry is cited as being particularly impacted by the 1988-1989 drought included food processing firms, electrical machinery manufacturers, and non-electric machinery industries.

CONCLUSIONS

As in 1988, the most important follow-on impacts of the 1988 drought, and the most important impacts during the first nine months of 1989 from the "1989 drought," were to the agricultural sector. The 1989 drought in the central High Plains and western Corn Belt provided two major negative impacts, one to the winter wheat belt centered in Kansas, and the other to livestock producers in the High Plains and western Corn Belts. Rises in food prices in 1989 due to drought became double (7% vs. 3%) that predicted by USDA in November 1988. Ripple effects from the 1988 drought were still being felt in the midwestern Corn and Soybean Belt and to various agribusinesses involved in selling equipment, fertilizer, and insurance for the 1989 crop season. The 1988 drought continued up through the summer of 1989 in the western Corn Belt and northern High Plains, leading to 10 to 20% reductions in corn, wheat, and soybean yields.

In summary, the fall (1988)-winter-spring-summer (1989) drought acted initially to limit winter wheat planting by 12% in the winter (red) wheat belt. The drought conditions led to production reductions of 23% of average. This meant (assuming average yields of spring wheat in 1989) that the 1989 total U.S. wheat production would be decreased by 8% from that in 1988 (which itself was down 21% from average). The net effects of the 1988-89 drought were an ever deepening reduction of U.S. wheat stocks as set at 2.36 billion bushels on June 1, 1987; dropping to 1.85 billion bushels a year later (June 1, 1988); and dropping to only 549 million bushels by June 1, 1989. This will lead U.S. exports of wheat to decrease by 300 million bushels in the year beginning on June 1, 1989. Corn stocks continued to drop in 1989 as drought effects reduced yields below government expectations.

Government policies relating to the 1989 drought problems (initially livestock and winter wheat farming; later corn and spring wheat) reflected continuing confusion over the use of direct relief versus use of crop insurance; debates over the formulation of a 1989 Farm Relief Bill; and differences between Congress and the Administration in how and when to provide farm relief.

A major factor affecting the management of agricultural and other resources, as well as policy development, was a continuing uncertainty over the drought's status and its effect, particularly in agriculture. From climatic measurements, the drought was present throughout the winter of 1988-89, spring of 1989, and summer of 1989 in large parts of the United States. Climatic probabilities issued in late 1988 indicated that large sectors of the United States would remain in drought throughout the spring and summer of 1989. Yet, some meteorologists proclaimed during mid-winter and late spring, that the drought was dissipating or would dissipate, and a tone of optimism reflected the policy of the Administration towards drought effects on summer crops. The lack of recognition of the drought problem is reflected in the continuing downgrading by the USDA of its corn production estimates: on March 1 they estimated U.S. production for 1989 as 7.85 billion bushels, this was dropped on July 1 to 7.45 billion, and then to 7.35 billion on August 1. Thus, grain surpluses expected at the end of 1989 were being predicted in mid-summer 1989 as much lower than had been forecast in the fall, winter, and spring of 1988-1989.

Several environmental effects estimated or largely unknown from the 1988 drought became more evident during 1989. This included changes in populations of insect pests and damages to forests and tree crops. Water supply problems in the areas of deepening drought in the southwest continued to increase in 1989. Water hauling was common in several parts of Iowa as the water rationing in communities in parts of Missouri, Iowa, and Illinois. Above average western forest fires had emerged again in July and August 1989.

Scientists who assessed, monitored, informed, and predicted the 1989 drought conditions continued to obfuscate the situation by their conflicting views. Certain prognosticators tended to be optimistic about 1989 drought conditions, whereas most other assessors were more pessimistic. The confusion resulting from the widely varying scientific views of the drought hindered decision making.

RECOMMENDATIONS

The objectives of this report, were three-fold. First, the impacts of the continuing drought of 1988-89 on the United States were to be measured. Then, the ensuing policy reactions and their implications for future U.S. policy were to be described. The final objective was to assess how these impacts and adjustments relate to the nation's existing climate services as well as assess how any on-going federal legislation affected this process. In achieving the third objective, I have drawn on the findings to develop recommendations for action related to climate aberrations. These recommendations call for actions that would enhance the nation's ability to more intelligently manage its natural resources and enhance its economy.

The nation's five Regional Climate Centers (in the Northeast, Southeast, Midwest, High Plains, and Far West), the National Climate Data Center of NOAA, and the Climate Analysis Center of NOAA provided climate data and impacts information useful in the study. However, considerable information on the impacts and adjustments to the drought was gleaned from other sources. This points to the first recommendation:

These climate centers, in concert with other federal and state agencies, need to develop better, more responsive procedures for interpreting climate impacts occurring in key sectors (water, agriculture, transportation, human health, and natural resources). Improvements will require research to develop and improve existing climate-impact relationships, and the development of an institutional infrastructure to focus on assessment of climate impacts to the environment and the economy.

The evidence was strong that the atmospheric sciences community frequently provided federal, state, and local decision makers, as well as the general public, with conflicting assessments of the causes of the drought, the current condition of the drought, and the future of the drought. This led to confusion amongst the general public and detrimentally affected decision makers; delayed and often led to incorrect (or inefficient) reactions by impacted groups and business sectors; and limited wise policy development, particularly in the agricultural sector. This finding leads to a second recommendation.

The federal government should establish a National Climate Service in NOAA, a system that a) ensures that climate data and information are quickly gathered, assessed for accuracy, interpreted as to possible impacts, and made widely available; and b) provides these national and regional results through <u>national and regional climate centers acting as informational clearinghouses</u>.

The National Climate Program Office, in concert with the Regional Climate Centers, the Climate Analysis Center, and the National Climatic Data Center, has attempted for two years to establish the above system and implement essential improvements in the climate impact assessment research, as part of the terms of the National Climate Program Act. These efforts have been frustrated by the lack of funding and attention to these matters within NOAA, and by the lack of interest by other federal agencies in addressing applied climate problems and improved services. This study of the 1988-89 drought revealed that adjustments in the federal level were greatly hampered by the lack of a **standing interagency task force** to assess the national impacts and provide policy guidance. Congress has proposed 1989 legislation, as part of the effort to establish a global change program, that if enacted would critically weaken the National Climate Program. This in turn would be counterproductive as the National Climate Program Office has been instrumental in urging improvements in the nation's climate services effort. Other proposed 1989 legislation would enhance the climate services for agriculture. As a result, the following recommendations are made:

First, the federal government should establish a standing interagency committee under the National Climate Program that has the responsibilities for constantly monitoring climate aberrations affecting the United States; for informing agency leaders; and for ensuring that timely climate impact assessments (recommendation number one above) are performed.

Second, the National Climate Program Act should be modified to embrace the actions needed to accomplish these tasks and the provisions of the proposed agricultural legislation (and all national services that are beyond the scope of a global change research program), and legislation that would alter and weaken the National Climate Program should be discouraged.

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